LAND MANAGEMENT HANDBOOK

8

Effects of Operational Brushing on Conifers and Plant Communities in the Southern Interior of British Columbia

Results from *PROBE* 1991–2000 PRotocol for Operational Brushing Evaluations

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Effects of Operational Brushing on Conifers and Plant Communities in the Southern Interior of British Columbia

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Results from PROBE 1991–2000
PRotocol for Operational Brushing Evaluations

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This Land Management Handbook contains a large amount of information on the effects of operational brushing treatments on conifers and plant communities in the Kamloops and Nelson forest regions. Data were collected over a 9-year period from 96 individual PROBE (PRotocol for Operational Brushing Evaluations) trials, and detailed parametric statistical analysis has now been carried out for eight different vegetation complexes. We have organized this document primarily by vegetation complex, so that information for each of the eight complexes is presented in individual sections that essentially "stand-alone." Each of these sections contains an abstract, an introduction, site descriptions, results, a discussion, conclusions, and management implications (Sections 4–11).* The overall introduction, objectives, and methodology are contained in Sections 1–3, and an overall summary and management recommendation are presented in Section 12. Readers are referred to the overall summary and section abstracts for a quick synopsis of the study results. We could not include all PROBE sites in the analysis because not all combinations of "vegetation complex–brushing treatment–biogeoclimatic unit–conifer species" have been adequately replicated. Results from unreplicated treatments are summarized in the Appendices.

Here is a brief description of the contents of each section of this report:

Section 1—Introduction: A description of the overall approach and scope of the PROBE program, as well as its relevance to silvicultural treatment effectiveness measurement and monitoring in British Columbia.

Section 2—Objectives: Specific objectives of the PROBE program.

Section 3—Methods: A description of the experimental design, methods of data collection, and methods of data analysis.

Section 4—*Fireweed* Complex:
Manual brushing to release Engelmann spruce in the ESSF/ICH zones
Manual brushing to release lodgepole pine in the ICH/ESSF zones
Foliar glyphosate application to release Engelmann spruce in the ESSF/ICH zones
Grazing treatments to release Engelmann spruce in the ESSF zone

Section 5—*Fern* Complex:
Foliar glyphosate application to release hybrid spruce in the ICH zone

Section 6—*Mixed Shrub* Complex:
Manual brushing to release hybrid spruce in the ICH/ESSF zones
Grazing treatments to release hybrid spruce in the ICH/ESSF zones

Section 7—*Ericaceous Shrub* and *Subalpine Herb* Complexes:
Manual brushing of the *Ericaceous Shrub* Complex to release Engelmann spruce in the ESSF zone

Section 8—*Dry Alder* Complex:
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Section 9—*Wet Alder* Complex:
Manual brushing to release Engelmann spruce in the ESSF zone

Section 10—*Aspen* Complex:
Manual brushing to release lodgepole pine in the IDF/MS zones

Section 11—*Mixed Broadleaf-Shrub* Complex:
Manual brushing to release Douglas-fir in the ICH/IDF zones
Manual brushing to release lodgepole pine in the ICH zone
Cut stump–glyphosate treatment to release Douglas-fir in the ICH zone
Girdling to release Douglas-fir in the ICH zone

Section 12—Overall summary: An overall summary of PROBE findings and their implications for forest management in the southern interior of British Columbia.

Section 13—References: A list of all published and unpublished cited material.

Appendix 1—Information about the *Willow* and *Pinegrass* Complexes and a summary of results for unreplicated treatments involving these communities.

Appendix 2—Summary tables containing information about PROBE sites that presently represent unreplicated treatment cells.

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* This organization allows readers to refer only to the vegetation complex that they are interested in.

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This report is the co-operative work of five authors who together designed the layout of the report. Jean Heineman is the principal author of the following sections: *Fireweed* Complex, *Ericaceous Shrub* and *Subalpine Herb* Complexes, *Wet Alder* Complex, *Pinegrass* Complex, and *Willow* Complex sections. She also assisted with the Introduction and Methods sections. Jean Mather is the principal author of the *Fern* Complex, *Mixed Shrub* Complex, *Dry Alder* Complex, *Aspen* Complex, and *Mixed Broadleaf-Shrub* Complex sections. Suzanne Simard authored the Competition Thresholds sections, Overall Summary, co-authored the Introduction and Methods sections, and edited several drafts of the full report. Jean Heineman assumed the difficult task of putting all of the separate sections into a standard format. Don Sachs was responsible for all aspects of data analysis. This included database management, statistical consultation, SAS program development, graphics, and statistical interpretation. Alan Vyse has been involved with the project since its initiation, and has assisted with design and interpretation, extension, advancement, and funding acquisition. He also provided considerable input to the *Ericaceous Shrub* section and the Overall Summary.

PROBE was initiated in 1990–1991 by Suzanne Simard when she wrote the original protocol (Land Management Report 86). We thank the many foresters who originally supported the concept of this vegetation monitoring program, including Ron Gray, Rob Enfield, Bill Nash, Dave Horne, Don Purdy, and Jim Wright. We thank the following people for reviewing the PROBE protocol: Wendy Bergerud, Dave Clark, Dave Coates, Phil Comeau, Brian D'Anjou, Winn Hayes-Byl, Graeme Hope, Teresa Newsome, John Pollack, Gerry Reichenbach, and Chris Thompson. The original protocol was first tested in the field in 1991 by Jean Mather and Fred Newhouse, who provided input for revisions to the field methodology. In 1994, Jean Mather wrote an addendum to the protocol to clarify and expand on data-collection and reporting methods.

Since the onset, Suzanne Simard has managed the PROBE program, including all aspects of design, delivery, extension, advancement, and funding acquisition. Barbara Zimonick has assisted with administration of the PROBE program, and Jean Mather has co-ordinated field crews and assisted with management of the sampling matrix. Jean Mather was the principal author of PROBE memos, which pre-dated this report.

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SECTION 1

INTRODUCTION

PROBE (PRotocol for Operational Brushing Evaluations) is a large-scale vegetation management study examining the effects of operational brushing treatments on conifers and plant communities in the southern interior of British Columbia (Simard 1993). It was developed and funded in 1991 in response to a request to quantify the costs and benefits of operational brushing by the forest districts and licensees, in view of the increasing expenditures for brushing in the Kamloops and Nelson forest regions. In 1997/98, brushing operations were carried out on 9839 ha in the Kamloops Forest Region (Figure 1) and 8697 ha in the Nelson Forest Region (Figure 2), at costs ranging between $248 and $799 per ha (Table 1), for an estimated total expenditure of approximately $9.5 million.

Brushing programs had grown enormously between 1981 and 1991 (Figures 1 and 2), and increased even further through 1998, mainly due to efforts to prevent plantation loss on backlog sites (pre-1987). Brushing treatments on current sites (post-1987) were also becoming more common, however, which contributed to the overall growth

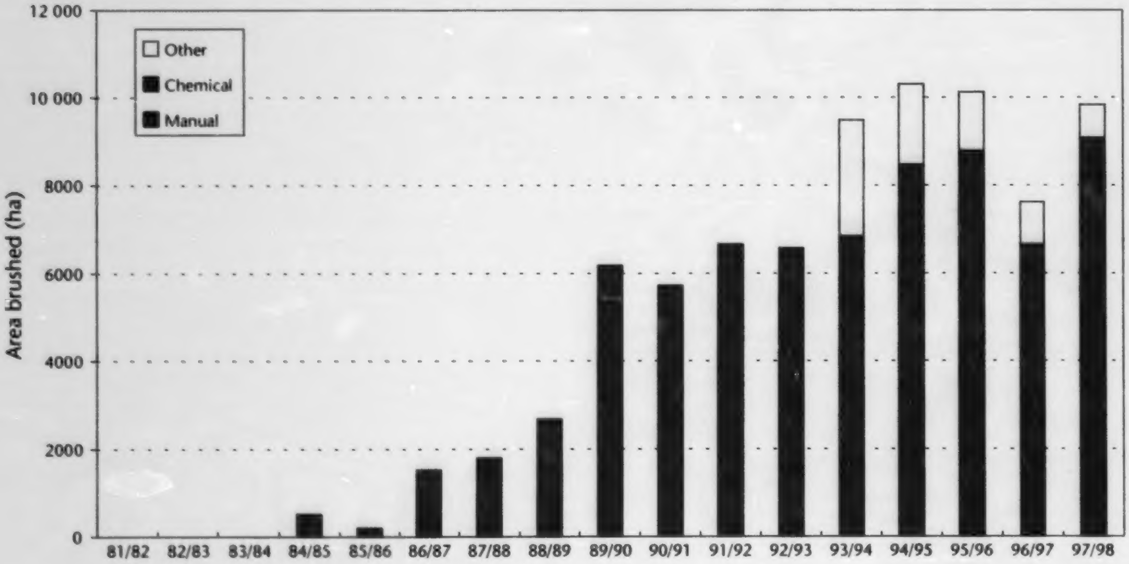

FIGURE 1 *Brushing trends in the Kamloops Forest Region from 1981 to 1998 (B.C. Ministry of Forests 1995b, 1996, 1997, 1998).*

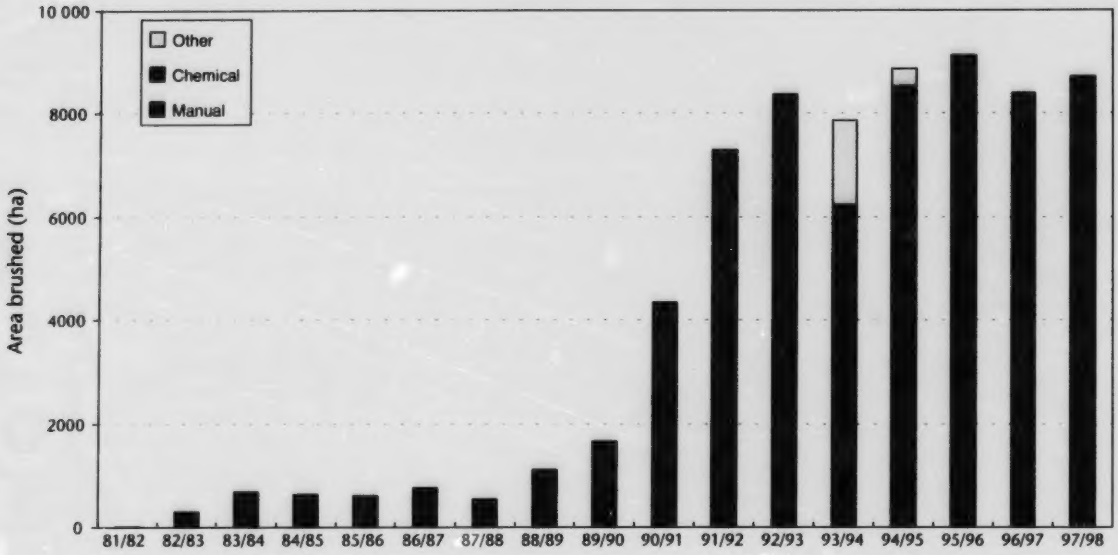

FIGURE 2 *Brushing trends in the Nelson Forest Region from 1981 to 1998 (B.C. Ministry of Forests 1995b, 1996, 1997, 1998).*

TABLE 1 *Average brushing costs per hectare in 1997–98*[a]

	Kamloops Region	Nelson Region	Average across British Columbia
Motorized manual	$474	$601	$531
Non-motorized manual	$499	$522	$562
Ground chemical application	$799	$601	$735
Grazing	$248	n/a	$359

[a] Annual report, B.C. Ministry of Forests (1999)

of vegetation management programs. However, insufficient data were available to say whether brushing treatments were improving conifer performance or helping meet free-growing objectives with regard to stocking, conifer size, and the height relationships between conifers and surrounding vegetation. Increases in brushing programs were largely funded by the Canada-British Columbia Forest Resource Development Agreement (FRDA) and Forest Renewal British Columbia (FRBC), which were aimed at returning backlog NSR (Not Satisfactorily Restocked) areas to conifer production.

PROBE is designed to determine the effects of brushing treatments on the performance of young conifers. It also documents treatment effects on species and structural diversity of the vascular plant community. Silviculturists wished to know how the structure, composition, and vigour of plant communities were affected by common brushing treatments, particularly where herbicides were applied. Maintenance of biodiversity is becoming increasingly important in British Columbia forest management as a result of public pressure (Burton et al. 1992), the enactment of the Forest Practices Code (B.C. Ministry of Forests 1995a), and the development of certification standards (Upton and Bass 1996; Kimmins 1997). The need for measuring short- and long-term effects of basic and intensive silviculture activities on the forest resource, both expected and unintended, is increasingly recognized by the B.C. Ministry of Forests and Forest Renewal BC. In an economic assessment of Forest Renewal BC silviculture programs, the Auditor General of British Columbia found there was "a lack of understanding of the real biological impacts" of its silviculture treatments, and recommended that the corporation "conduct further monitoring to ensure there is adequate information about the short-term impacts of its programs, both positive and negative" (B.C. Office of the Auditor General 1999). PROBE is one program aimed at measuring these impacts with regard to operational brushing.

The objectives of PROBE are to study the effects of vegetation management treatments on survival, growth, health, and free-growing status of conifers, and on the structure, diversity, and condition of the plant community. Brushing effects are being studied within 13 vegetation complexes that potentially threaten the performance of conifer seedlings in southern interior British Columbia (Kimmins and Comeau 1990). The brushing treatments being tested have been commonly applied during the study period from 1991 to 1999. To ensure that the most problematic plant communities, common brushing treatments, and commonly planted conifer species were being studied, site selection was guided by a treatment sampling matrix established in consultation with the forest districts and licensees (Table 2).

PROBE differs from most vegetation management research studies in its objectives and methods, which has important implications for interpretation of results. The differences help explain why the magnitude of conifer response to brushing measured in PROBE is usually less than that measured in some research studies. First, the overarching objective of PROBE is to evaluate silviculture treatment effectiveness at reaching ecological and operational objectives. In contrast, research objectives often focus on quantifying inter- and intra-specific competition, determining the underlying competitive mechanisms, and examining how and why various ecosystem components are affected. Second, PROBE reaches its objectives by comparing operationally treated areas with an untreated control, whereas many vegetation management research studies examine response to a broad range in competition levels, including maximum and minimum vegetation abundance. Consequently, PROBE measures response to "average" treatment conditions, whereas many research studies measure "potential" response (e.g., potential growth response of conifers to complete vegetation removal). Third, PROBE tests brushing treatment effectiveness under operational conditions, which are characterized by variability in plant community and treatment attributes, whereas research studies usually attempt to minimize confounding factors by selecting for uniformity in vegetation complexes and treatment application. The latter approach helps identify mechanisms that underlie conifer response, but the results are not directly applicable to highly variable operational conditions. Fourth, approximately one-third of the sites evaluated with PROBE were current (harvested post-1987), where improved site preparation and planting have reduced vegetation competitive environments. In contrast, much British Columbia vegetation management research has historically been conducted on backlog sites (harvested pre-1987), where vegetation communities were more fully developed and competition much more severe. Finally, PROBE replicates treatments across several geographically distinct sites, whereas most research studies are located on one or two sites that are in close proximity. PROBE replicates of a particular treatment cell are comparable in ecosystem, vegetation complex, conifer target species, and brushing treatment, but they may vary in site history and year of establishment. Consequently, PROBE treatment cells are comprised of more variable replicates than most research studies, which can reduce power of the statistical test, but they also have broader scope of inference. The experimental design used in PROBE is equally as rigorous, and actually avoids pseudo-replication and the narrow scope of inference that characterize some vegetation management research studies.

The PROBE program is designed to evaluate silviculture treatment effectiveness at reaching ecological and operational objectives, and the results should be used accordingly to modify stand-level silviculture prescriptions. It was not designed to monitor growth and yield of treated stands, and therefore cannot be used directly in timber supply analysis (TSA) or assimilated in allowable annual cut (AAC) determinations for two reasons, which apply equally to all silvicultural research trials. First, growth and yield monitoring for TSA and AAC purposes requires random selection of stands from a defined population of stands, random selection of monitoring areas within stands, and random assignment of treatments and controls within the monitoring areas. PROBE randomly selects stands from a list of candidate stands being treated in a particular year, but it cannot randomly select from the entire population of similarly treated stands because not all stands are treated or sampled in a single year. However, PROBE does randomly assign treatments and controls within a stand. Second, PROBE measures early stand responses to treatment (1–15 years) and therefore does not include growth and yield measurements

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TABLE 2 *Treatment matrix used to guide selection of* PROBE *sites. Shading indicates treatment cells where* PROBE *installations presently exist (number of replicate sites and number of measurement years, in parentheses, to the end of 1999) or where they have not yet been established due to lack of opportunity or funding (indicated by "0"). In unshaded areas, "U" indicates treatments that are uncommonly applied to a particular vegetation complex and "X" indicates treatments that are not appropriate for the complex.*

Complex	BEC zone	Tree species	Manual cutting[a]	Partial manual[b]	Girdling[c]	Glyphosate spray[d]	Cut stump glyphosate[e]	Cut and spray glyphosate[f]	Basal triclopyr[g]	Grazing[h]	Mulch mats[i]
Herb and low-elevation shrub complexes											
Fireweed	ICH, ESSF	Pl	3 (5 year)	X	X	2	X	X	X	0	0
		Sx	3 (3 year)	X	X	3 (5 year)	X	X	X	3 (1 year)	2
		Fd	2	X	X	1	X	X	X	0	0
Fern	ICH	Sx	0	X	X	3 (5 year)	X	X	X	0	0
Subalpine herb	ESSF	Se	0	X	X	0	X	X	X	1	0
Pinegrass	IDF, MS	Pl	1	X	X	1	X	X	X	0	0
		Fd	0	X	X	0	X	X	X	0	0
Mixed shrub	ICH, ESSF	Sx	3 (3 year)	X	X	0	X	X	X	3 (1 year)	X
		Fd	1	X	X	1	X	X	X	0	X
		Pl	0	X	X	0	X	X	X	0	X
		Cw	1	X	X	1	X	X	X	0	X
Dry shrub	IDF, ICH	Pl	1	X	X	0	X	X	X	0	X
		Fd	0	X	X	0	X	X	X	0	X
High-elevation shrub complexes											
Ericaceous shrub	ESSF	Pl	0	X	X	0	X	X	X	0	X
		Se	4 (5 year)	X	X	2	X	X	X	0	X
Tall shrub complexes											
Dry alder	IDF, MS	Pl	3 (5 year)	X	X	1	U	U	U	X	X
		Sx	1			0	U	U	U	X	X
Wet alder	ICH, ESSF	Sx	3 (3 year)	X	X	0	0	0	U	X	X
		Pl	0	X	X	0	0	0	U	X	X
Willow	IDF, ICH, MS, ESSF	Fd	0	X	X	1	U	0	U	X	X

TABLE 2 *Continued*

Complex	BGC zone	Tree species	Manual cutting[a]	Partial manual[b]	Girdling[c]	Glyphosate spray[d]	Cut stump glyphosate[e]	Cut and spray glyphosate[f]	Basal triclopyr[g]	Grazing[h]	Mulch mats[i]
Broadleaf complexes											
Aspen	IDF, MS	Pl	3 (3 year)	1	0	0	0	0	2	X	X
		Fd	0	0	0	0	0	0	0	X	X
	ICH	Pl	1	2	0	0	0	1	0	X	X
		Fd	2	0	2	0	0	0	0	X	X
Mixed Broadleaf-Shrub	IDF, ICH	Fd	3 (5 year)	2	3 (5 year)	0	3 (5 year)	1	2	X	X
		Pl	3 (5 year)	0	0	1	0	0	0	X	X
		Sx	2	0	0	1	0	0	0	X	X
		Cw	0	0	0	0	1	0	0	X	X
Cottonwood–Shrub	IDF, ICH	Se	0	0	0	0	0	0	0	X	X

[a] Manual cutting = using motorized or non-motorized tools to cut vegetation

[b] Partial manual = using motorized tools to cut vegetation, leaving a designated density of standing broadleaves (i.e., 400, 1000, or 4000 stems/ha)

[c] Girdling = using a chain girdler to cut through the bark around the circumference of each broadleaf stem

[d] Glyphosate spray = broadcast or spot application of glyphosate solution (usually 1.4–2.1 kg ai/ha) using backpack sprayers or broadcast aerial application

[e] Cut stump–glyphosate treatment = manual cutting followed by the application of glyphosate solution to cut stumps

[f] Cut and spray glyphosate treatment = manual cutting 1 year, followed by application of glyphosate solution to sprouts the following year

[g] Basal triclopyr application = wiping triclopyr in an oil carrier onto broadleaf stems

[h] Grazing = the use of sheep or cattle to reduce the abundance of vegetation around seedlings

[i] Mulch mats = mats are laid around seedling stems to prevent growth of vegetation

TABLE 2 *Treatment matrix used to guide selection of* PROBE *sites. Shading indicates treatment cells where* PROBE *installations presently exist (number of replicate sites and number of measurement years, in parentheses, to the end of 1999) or where they have not yet been established due to lack of opportunity or funding (indicated by "0"). In unshaded areas, "U" indicates treatments that are uncommonly applied to a particular vegetation complex and "X" indicates treatments that are not appropriate for the complex.*

Complex	BEC zone	Tree species	Manual cutting[a]	Partial manual[b]	Girdling[c]	Glyphosate spray[d]	Cut stump glyphosate[e]	Cut and spray glyphosate[f]	Basal triclopyr[g]	Grazing[h]	Mulch mats[i]
Herb and low-elevation shrub complexes											
Fireweed	ICH, ESSF	Pl	3 (5 year)	X	X	2	X	X	X	0	0
		Sx	3 (3 year)	X	X	3 (5 year)	X	X	X	3 (1 year)	2
		Fd	2	X	X	1	X	X	X	0	0
Fern	ICH	Sx	0	X	X	3 (5 year)	X	X	X	0	0
Subalpine herb	ESSF	Se	0	X	X	0	X	X	X	1	0
Pinegrass	IDF, MS	Pl	1	X	X	1	X	X	X	0	0
		Fd	0	X	X	0	X	X	X	0	0
Mixed shrub	ICH, ESSF	Sx	3 (3 year)	X	X	0	X	X	X	3 (1 year)	X
		Fd	1	X	X	1	X	X	X	0	X
		Pl	0	X	X	0	X	X	X	0	X
		Cw	1	X	X	1	X	X	X	0	X
Dry shrub	IDF, ICH	Pl	1	X	X	0	X	X	X	0	X
		Fd	0	X	X	0	X	X	X	0	X
High-elevation shrub complexes											
Ericaceous shrub	ESSF	Pl	0	X	X	0	X	X	X	0	X
		Se	4 (5 year)	X	X	2	X	X	X	0	X
Tall shrub complexes											
Dry alder	IDF, MS	Pl	3 (5 year)	X	X	1	U	U	U	X	X
		Sx	1			0	U	U	U	X	X
Wet alder	ICH, ESSF	Sx	3 (3 year)	X	X	0	0	0	U	X	X
		Pl	0	X	X	0	0	0	U	X	X
Willow	IDF, ICH, MS, ESSF	Fd	0	X	X	1	U	0	U	X	X

TABLE 2 *Continued*

Complex	BGC zone	Tree species	Manual cutting[a]	Partial manual[b]	Girdling[c]	Glyphosate spray[d]	Cut stump glyphosate[e]	Cut and spray glyphosate[f]	Basal triclopyr[g]	Grazing[h]	Mulch mats[i]
Broadleaf complexes											
Aspen	IDF, MS	Pl	3 (3 year)	1	0	0	0	0	2	X	X
		Fd	0	0	0	0	0	0	0	X	X
	ICH	Pl	1	2	0	0	0	1	0	X	X
		Fd	2	0	2	0	0	0	0	X	X
Mixed Broadleaf-Shrub	IDF, ICH	Fd	3 (5 year)	2	3 (5 year)	0	3 (5 year)	1	2	X	X
		Pl	3 (5 year)	0	0	1	0	0	0	X	X
		Sx	2	0	0	1	0	0	0	X	X
		Cw	0	0	0	0	1	0	0	X	X
Cottonwood–Shrub	IDF, ICH	Se	0	0	0	0	0	0	0	X	X

[a] Manual cutting = using motorized or non-motorized tools to cut vegetation
[b] Partial manual = using motorized tools to cut vegetation, leaving a designated density of standing broadleaves (i.e., 400, 1000, or 4000 stems/ha)
[c] Girdling = using a chain girdler to cut through the bark around the circumference of each broadleaf stem
[d] Glyphosate spray = broadcast or spot application of glyphosate solution (usually 1.4–2.1 kg ai/ha) using backpack sprayers or broadcast aerial application
[e] Cut stump–glyphosate treatment = manual cutting followed by the application of glyphosate solution to cut stumps
[f] Cut and spray glyphosate treatment = manual cutting 1 year, followed by application of glyphosate solution to sprouts the following year
[g] Basal triclopyr application = wiping triclopyr in an oil carrier onto broadleaf stems
[h] Grazing = the use of sheep or cattle to reduce the abundance of vegetation around seedlings
[i] Mulch mats = mats are laid around seedling stems to prevent growth of vegetation

as defined by the Silviculture Working Group (1997). However, PROBE trials were designed to accommodate growth and yield plots, and some trials have had growth and yield plots established within them using the EXPLORE protocol (Biring et al. 1998).

A large network of growth and yield plots is currently in place in British Columbia and the data are used in TSA and AAC determinations. However, there are a number of reasons why it is not useful in detecting silviculture treatment effects. First, the strict requirements of the growth and yield program for randomization and replication preclude comparisons of silviculturally treated and untreated stands, as is done in PROBE, because silviculture treatments are not randomly allocated across the landscape. As a result, silviculture treatment effects are inextricably confounded with site and initial stand conditions. Second, detection of significant differences between treatments at the accuracy required for silviculture treatment adjustments is not possible because the number and distribution of growth and yield monitoring plots is too small to address the variability in stand attributes. For these reasons, it has been recommended that monitoring growth and yield responses to silviculture treatments at the forest or stand level is not feasible. Instead of using the growth and yield monitoring program, it has been recommended that treatment response estimates be obtained from statistically designed trials outside the growth and yield monitoring program (J. S. Thrower & Associates Ltd. 1999). These trials can be established with operationally applied treatments to quantify "real-world" responses (e.g., PROBE), or they can be research trials where many stand factors are controlled to isolate specific treatment or stand attribute effects and determine causal relationships. PROBE meets all of the criteria for statistical inference (randomization and replication of treatments and controls), and has been reported as using an excellent experimental design for measuring silviculture treatment response and inferring silviculture treatment effectiveness to the sampled population (Bergerud 1996).

Five programs besides PROBE are examining effects of operational brushing treatments on crop tree responses and other ecological and operational attributes in British Columbia. These programs are Operational Herbicide Monitoring (OHM) (Hays 1990), Northern Interior Vegetation Management Association (NIVMA) Unified System of Silviculture Monitoring (USSM) (NIVMA 1990), NIVMA Treatment Regime Evaluation—Numerical Decision Support (TRENDS) (NIVMA 1996), Experimental Design Protocol for Long-term Operational Response Evaluations (EXPLORE) (Biring et al. 1998), and Regional Vegetation Management Model (RVMM) (Shula and Knowe 1991). These programs have been reviewed from a vegetation management perspective by Biring et al. (1998) and Simard (1993). Most of the vegetation management programs, as well as the Intensive Forest Management (IFM) Installations and the Silviculturally Treated (ST) program, have also been reviewed from a growth and yield monitoring perspective by J. S. Thrower & Associates (1999). PROBE is most similar to EXPLORE in that operationally brushed treatments are compared with controls using randomly assigned paired plots replicated in geographically distinct blocks (allowing for measurement of treatment response). It differs from EXPLORE mainly in the absence of growth and yield measurements, although PROBE trials are designed to accommodate growth and yield plots when they reach the appropriate age. However, few EXPLORE plots have yet been installed. The USSM and TRENDS programs differ from PROBE in that control plots are not required, thus treatment response cannot be determined. In the case of TRENDS at least, installation blocks are randomly selected from defined populations of harvested blocks. Several attributes of these programs are compared in Table 3.

At present, the PROBE program includes 96 permanent installations in the Kamloops and Nelson forest regions that have been measured for 1–5 years post-treatment. In 1999, there was adequate replication of sites (i.e., at least three replicate sites per treatment unit) to carry out inductive parametric statistical analysis (e.g., analysis of variance) for five brushing treatments in eight of the 13 targeted vegetation complexes (Table 2).

This report is organized into 12 sections. Immediately following this Introduction (Section 1) is a description of the objectives (Section 2) and methods of PROBE (Section 3). The main body of the report is comprised of eight sections (Sections 4–11), one for each vegetation complex. For each complex, results are presented on a brushing treatment–ecosystem–target conifer species–specific basis. For organizational purposes, descriptions of

TABLE 3 *Comparison of programs used to monitor brushing efficacy in British Columbia (modified from Biring et al. 1998)*

Characteristic	OHM	USSM	PROBE	RVMM	TRENDS	EXPLORE
Protection buffer	≥ 10.0 m	50.0 m	30.0 m	–	variable	30.0 m
Treatment plot area	1.21 ha	0.36 ha	0.81 ha	–	variable	0.49 ha
Treated buffer (within treatment plot area)	20.0 m	15.0 m	20.0 m	–	variable	10.0 m
Treatment evaluations	mandatory	optional	mandatory	mandatory	optional	mandatory
Pre-harvest assessments	–	–	–	–	yes	yes
Pre-treatment assessments	yes	no	yes	–	yes	yes
Tree measurement plot size	1.21 ha*	0.005 ha ($50 m^2$)	0.49 ha†	0.05 ± 0.01 ha	0.09 ha	0.10 ha
Vegetation monitoring plot size	0.0005 ha ($5 m^2$)	0.0005 ha ($5 m^2$)	0.001 or 0.002 ha (10 or $20 m^2$)	0.004 ha ($40 m^2$)	0.023 ha	0.005 ha ($50 m^2$)
Vegetation monitoring plot number	20	2	36	4	4	4
Gridpoints per treatment	100	16	36	no	36	36
Soil disturbance assessment plot (site preparation)	–	–	36 subplots ($r = 1$ m)	–	2–180 m transect lines	50 m transect lines
Habitat monitoring plots per treatment	2	–	4	–	no	4
Habitat monitoring plot size	0.02 ha ($200 m^2$)	–	0.005 ha ($50 m^2$)	–	–	0.005 ha ($50 m^2$)
Coarse woody debris assessments	–	–	yes	–	yes	yes
Vascular plant biodiversity assessment	yes	optional	yes	–	yes	yes
Compatibility with growth and yield	no	no	no‡	yes	yes	yes

OHM = Operational Herbicide Monitoring
USSM = Unified System of Silviculture Monitoring
PROBE = Protocol for Operational Brushing Evaluations
RVMM = Regional Vegetation Management Model
TRENDS = Treatment Regime Evaluation—Numerical Decision Support
EXPLORE = Experimental Design Protocol for Long-term Operational Response Evaluations
* Seedling assessments are done on 100 trees distributed over a 1.21-ha (10-m grid) plot
† Seedling assessments are done on 36 trees distributed over a 0.49-m plot
‡ PROBE plots (0.49 ha) are large enough to accommodate growth and yield plots, such as those described by Biring et al. (1998)

relevant sites and treatments are included within each results section. A description of the vegetation complex is included in the introduction to each section, and a comparison of PROBE results with those of other research studies is made in each discussion. The report ends with an overall summary (Section 12) that summarizes the main findings and discusses their application in silvicultural decision-making. Information about vegetation complexes and treatment cells that were not analyzed because adequate replication had not yet been achieved is provided in the Appendices. Data or observations from individual PROBE sites that were not included in the analysis are occasionally cited to support discussion issues.

SECTION 2

OBJECTIVES

PROBE is intended to meet the following objectives with regard to operational brushing treatments applied to different vegetation complexes and ecosystems of southern interior British Columbia:

1. To quantify the effects of operational brushing treatments on conifer survival, growth, health, and free-growing status.
2. To quantify the effects of operational brushing treatments on plant species abundance, and the structure, diversity, and condition of the plant communities.
3. To identify, wherever possible, competition thresholds for conifer growth.
4. To discuss possible effects of operational brushing treatments on various ecosystem attributes.
5. To determine whether or not brushing treatments are meeting biological and management objectives.

SECTION 3

METHODS

The methods described here are more fully detailed in Simard (1993). The PROBE program strives to meet the basic criteria for measuring treatment response using statistical inference, which includes randomization and replication of treatments and controls. Several populations were studied, specifically defined based on their ecosystem (biogeoclimatic unit and site series), vegetation complex, conifer tree species, and operational brushing treatment received. All populations occurred in the Kamloops and Nelson forest regions. Installation sites were randomly selected from the list of sites available each year. It must be recognized, however, that the populations from which sites were randomly selected were small because of restrictions imposed by site uniformity criteria, number of suitable operational brushing projects, and availability of funding in a given year. Paired plots were subjectively located in each opening to ensure comparability in site and vegetation characteristics. Treatment and control designations were then randomly assigned to each of the paired plots.

Experimental Design

The PROBE program is composed of a series of separate brushing experiments that are individually defined by their particular combination of ecosystem–vegetation complex–target conifer species–brushing method (hereafter called treatment cell).

For each treatment cell, two treatments (brushing treatment, control) were replicated a minimum of three times in a randomized complete block design (RCBD). Each replicate block occurred on a separate opening in the Kamloops and Nelson forest regions (hereafter called PROBE site).

A matrix of treatment cells, based on common brushing treatments and vegetation complexes in southern interior British Columbia, was developed to guide PROBE site selection (Table 2). This matrix was developed and modified based on input from forest districts and licensees regarding common operational treatment application. Brushing treatments were included if they were frequently applied by more than one forest district in the Kamloops and Nelson forest regions. For example, manual cutting is the most commonly applied treatment in the southern interior, and therefore was given the highest priority for sampling. The vegetation complexes examined were previously identified as competitive threats to conifer crop trees and are fully described in Kimmins and Comeau (1990). Table 2 lists high priorities for vegetation management research, and indicates where PROBE sites have been or will be installed in the future. Other treatment cells in Table 2 are currently rare in operational brushing programs, and therefore are not currently being examined in the PROBE program. PROBE strives to accommodate new operational treatments, however, within the confines of annual funding availability.

Criteria for replicate site selection

Between 1991 and 1999, up to 15 PROBE sites were installed each year in the Kamloops and Nelson forest regions, depending on availability of funds. The funding restriction resulted in staggered replication of treatment cells over the 9-year period (i.e., full replication of a treatment cell occurred over several years rather than all within a single year). Fairly strict criteria for replicate site selection were also imposed so that between- and within-site variability did not overwhelm treatment responses. These factors resulted in a small population of appropriate sites for a particular treatment cell, from which PROBE sites were selected.

The population of potential PROBE sites for a particular treatment cell was identified through consultation with district or licensee representatives. All potential PROBE sites met the following criteria:

1. The site was considered in need of operational brushing.
2. The ecosystem, vegetation complex, conifer species, and brushing method for the site fell within PROBE high-priority research needs (Table 2).
3. The site had a medium moisture regime.
4. The site had been disturbed (i.e., harvested or site prepared) within the last 15 years.
5. The site had enough area with homogenous ecosystem characteristics and site history to allow establishment of two plots (brushing treatment and control) of approximately 0.8 ha each.

Location and installation of brushing treatment and control plots

Each PROBE installation consisted of two plots (brushing treatment and untreated control) that were installed prior to operational brushing. Plots were located to be representative of the area being brushed, and also to minimize site and stand variability between the brushing treatment and control plots (i.e., minimized within-site variability). A completely random approach to plot location was not taken because we expected that small treatment responses could be masked by between-plot variation. Brushing treatment and control plots were similar with regard to the following characteristics: slope (±10%), slope position, aspect (±45°), elevation (±50 m), soil texture, soil coarse fragment content, soil moisture regime, biogeoclimatic (BEC) site series, dominant vegetation species, and site preparation/planting history. Once plots were located, treatments (brushing and control) were randomly assigned.

Plots were either square (90 × 90 m) or rectangular (most often 70 × 120 m), including a 15–20 m buffer zone inside the perimeter of the plot (Figure 3). Inside the buffer zone of each of the brushing treatment and control plots, 36 tree-centred subplots were located in a square 6 × 6 grid (or a rectangular grid such as 9 × 4, depending on the plot configuration). This was done by locating the first gridpoint at a measured distance of 15–20 m inside one of the measurement plot corners, and then systematically locating six gridpoints at 10-m intervals along each of six gridlines. From each gridpoint, the closest, undamaged tree of the target conifer species was chosen as a subplot centre and tagged. Trees that were undamaged but unhealthy due to vegetation competition still qualified as "targets." Re-bar was placed 50 cm north of the crop tree to permanently mark the location of subplot centres. Subplot size varied with size of the target conifers: 10-m^2 subplots ($r = 1.78$ m) were used when average conifer height was ≤ 2 m and 20-m^2 subplots ($r = 2.52$ m) when average conifer height was >2 m. The same subplot size was used for all subplots within a given assessment period, but on some sites it changed from one assessment period to the next as conifers grew.

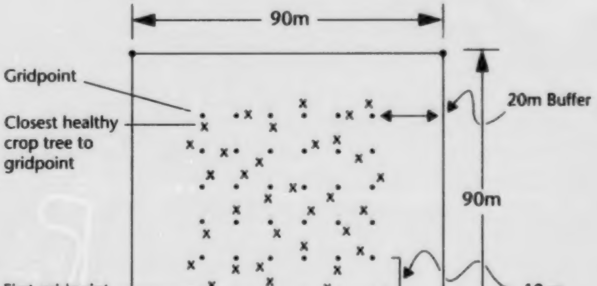
90m
Gridpoint
Closest healthy crop tree to gridpoint
20m Buffer
90m
10 m
First gridpoint randomly located

FIGURE 3 *Schematic diagram of a single treatment or control plot.*

Measurements

Measurement schedule

The PROBE measurement schedule specifies that information should be collected immediately before brushing, and 1, 3, 5, and 10 years afterward. However, none of the treatment cells reported here have yet exceeded 5 years; some have been measured for only 1 or 3 years. Conifer stocking surveys are scheduled to be carried out before brushing and 5 and 10 years afterward. The following information was collected at each assessment date:

1. Growth, survival, and condition of target conifer crop trees
2. Abundance and condition of target vegetation
3. Treatment effects on target woody vegetation
4. Abundance of all vascular plant species
5. Photographs from established photo-points

We recognize the potential for an "observer effect" in this project because several individuals were involved in carrying out the assessments. However, subjectivity was minimized, wherever possible, by having the same individuals carry out both pre- and post-treatment assessments on individual sites. Assessors were also required to participate in periodical reviews of the PROBE methodology to ensure that data were being collected in a consistent manner across all sites.

Conifers

Growth

Growth of the target conifer seedlings was assessed in the 36 subplots in each of the brushing treatment and control plots. Measured variables were: total height (ground level to apical bud), leader length (to apical bud), stem diameter (measured at root collar), crown length, and crown width (average of N–S, E–W measurements). Calculated variables were height:diameter ratio and stem diameter increment (change in stem diameter between measurement years). Damage to the foliage, leader, and stem that could potentially affect performance of the target conifer was also recorded according to Herring and Pollack (1985), and, if possible, the damage cause was noted using Silviculture Survey damage codes (B.C. Ministry of Forests 1989). Seedling vigour was visually assessed according to Herring and Pollack (1985) and Simard (1993) as follows:

- Good-vigour seedlings had vigorous shoot growth, large leaf area, long needles, deep green colour, and thick caliper.
- Moderate-vigour seedlings had moderate shoot growth, leaf area, needle length, and caliper.
- Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper.
- Moribund seedlings were near death with little or no shoot growth.
- Dead seedlings.

Competitive status was visually assessed according to Herring and Pollack (1985) and Simard (1993) as follows:

- "Free-of-vegetation" seedlings had leaders that were well above surrounding vegetation and were unlikely to become overtopped within two growing seasons.
- "Threatened" seedlings had leaders at approximately the same height as surrounding vegetation.
- "Overtopped" seedlings had leaders that were overtopped by vegetation.

Seedling survival rates were assessed using the frequency of dead trees. Mortality causes were determined by visual integration of damage causes and competitive status.

Stocking and density

Density of all species of conifers and stocking of well-spaced and free-growing trees were determined in the 36 subplots in each of the brushing treatment and control plots before and 5 years after brushing. This assessment will be repeated 10 years post-treatment. Established subplot centres were used, but instead of 10-m^2 or 20-m^2 subplots, stocking was assessed in 50-m^2 subplots ($r = 3.99$ m). A modification of the standard Silviculture Surveys procedure was used to assess stocking (B.C. Ministry of Forests 1989), and free-growing (with the exception of the minimum age criteria for some sites) was assessed using current standards (B.C. Ministry of Forests 1995a, 2000). Only free-growing results collected according to the old guidelines (B.C. Ministry of Forests 1995a) are reported in this document.

Vegetation

Abundance

The frequency of each potentially competitive species was assessed during the initial layout of treatment and control plots to facilitate selection of "target" species for repeated evaluation. Species were selected as targets if they represented, or could potentially represent, a competitive threat to crop trees, and if they occurred in at least 80% of subplots in both the brushing treatment and control in the pre-treatment assessment. An example of a "potential competitive threat" is fireweed in the understorey of paper birch in the *Mixed Broadleaf-Shrub* Complex. Fireweed may occur in minor, non-threatening amounts prior to treatment, but removal of the birch overstorey could create favourable conditions for its expansion to levels that are competitive with conifers. Selection of competitive or potentially competitive species or species groups (see below) was based on results of earlier studies in the southern interior (e.g., Simard 1990a, 1990b; Simard and Heineman 1996a, 1996b, 1996c; Simard, Heineman, and Youwe 1998). A minimum of one and a maximum of five target species were chosen on each site.

At each measurement, modal height and percent cover were estimated in each subplot for the selected target species as well as for the vegetation groups: "all vegetation," broadleaf trees, shrubs, and herbs. All broadleaf stems (regardless of origin) were counted in each subplot, and density per hectare was calculated.

Treatment efficacy

In vegetation complexes where broadleaf trees or shrubs with woody, persistent stems were chosen as target species, one stem of each of these species was chosen in, or near, each subplot and tagged for on-going assessment of treatment effects. Usually, the closest stem to the subplot centre was chosen, as long as it met criteria for brushing (e.g., if a girdling prescription called for treatment of all stems >5 cm diameter, then the tagged target specimen had to be >5 cm). Measured variables for target stems were total height and leader height. If leader growth was less than 80% complete, based on a subjective estimate, then the previous year's height growth was measured. Where sprouting had occurred in response to the brushing treatment, the number of sprouts was counted, and the average sprout length was estimated. Vigour was assessed according to Herring and Pollack (1985). Damage to the foliage, leader, and stem was also recorded according to Herring and Pollack (1985), and, if possible, the damage cause was noted using Silviculture Survey damage codes (B.C. Ministry of Forests 1989). The phenology of the vegetation complex (not the target specimen) at the time the brushing treatment was applied was recorded to help interpret treatment efficacy (Dierschke 1972; B.C. Ministry of Forests 1989). The efficacy of the chemical treatments for damaging the target specimen was rated using the Expert Committee on Weeds (ECW) rating system. ECW rating is based on subjective estimation of the level of vegetation control for a plant species, as evidenced by degree of top kill, defoliation, abnormal growth form, or mortality. A 0–100% rating scale was used, where 0 indicated no control and 100 indicated complete control (Walstad and Wagner 1982; Expert Committee on Weeds Abstracts 1983).

Richness and diversity of individual vascular plant species

Abundance of individual vascular plant species was measured in four 50-m² subplots, in each of the brushing treatment and untreated control, at each scheduled measurement. Subplots were crop-tree centred, and were randomly selected from the 36 subplots in the treatment and control plots during the pre-treatment measurement. The same subplots were monitored in subsequent measurement years. For each vascular plant species, stratum, percent cover, distribution, and vigour were recorded (Habitat Monitoring Committee 1990), although here we report only percent cover. This information was used to identify trends in the effects of brushing on richness, diversity, and abundance of individual species within each PROBE treatment cell. It also contributed to the provincial Habitat Monitoring database.

Vascular plant species data were used to determine species richness (the number of species) in the treatment and control plots, and to calculate diversity indices according to Simpson (1949)

$$[1] \qquad SDI = 1 - \sum_{i=1}((n_i/N)^2)$$

and Shannon and Weaver (1949)

$$[2] \qquad H = -(\sum_{i=1}(n_i/N)\log(n_i/N))$$

where n = cover of each species and N = sum of cover of all species.

Trends in brushing effects on individual plant species were identified by examining consistent increases and decreases in the abundance of individual species across a minimum of two replicate sites. The procedure for identifying these trends was necessarily subjective because it involved examining the data on a site-by-site basis, and attempting to exclude changes that were due to differences in assessment date, increased or decreased visibility of the species in question (particularly for herbs of very small stature), and assessor subjectivity.

Richness and diversity of vegetation groups

The percent cover data for individual vascular species were also used to study the richness and diversity of vegetation groups, which were defined based on plant growth forms. We defined eight vegetation groups:

1. Shade-tolerant conifers (e.g., western redcedar [*Thuja plicata*], western hemlock [*Tsuga heterophylla*], subalpine fir [*Abies lasiocarpa*])
2. Moderately shade tolerant conifers (e.g., Douglas-fir [*Pseudotsuga menziesii*], Engelmann spruce [*Picea engelmannii*], lodgepole pine [*Pinus contorta* var. *latifolia*])
3. Shade-intolerant conifers (e.g., western larch [*Larix occidentalis*], ponderosa pine [*Pinus ponderosa*])
4. Tall broadleaves (e.g., trembling aspen [*Populus tremuloides*], paper birch [*Betula papyrifera*], black cottonwood [*Populus trichocarpa*])
5. Tall shrubs, short broadleaves, short conifers (e.g., willow [*Salix* spp.], alder [*Alnus* spp.], cherry [*Prunus* spp.], yew [*Taxus brevifolia*])
6. Short shrubs (e.g., blueberry and huckleberry [*Vaccinium* spp.], white-flowered rhododendron [*Rhododendron albiflorum*], thimbleberry [*Rubus parviflorus*])
7. Tall herbs (e.g., fireweed [*Epilobium angustifolium*], Sitka valerian [*Valeriana sitchensis*], Indian hellebore [*Veratrum viride*])
8. Short herbs (e.g., oak fern [*Gymnocarpium dryopteris*], foamflower [*Tiarella* spp.], sedges [*Carex* spp.])

Each of the vascular plant species was assigned to one of the eight vegetation groups, and then group richness and diversity were calculated for each site. Richness was the number of vegetation groups that occurred. Diversity was calculated using Simpson [1] and Shannon-Weaver Diversity Indices [2], but where n = cover of each vegetation group and N = sum of cover of all vegetation groups.

Statistical Analysis

Between 1991 and 1998, 96 PROBE sites were installed and maintained, resulting in full replication of 15 treatment cells and partial replication of another 30 cells. The focus of this report is the fully replicated treatment cells, for which Analysis of Variance (ANOVA) was conducted separately for each measurement year. For individual sites in the partially replicated treatment cells, summary statistics were generated to provide qualitative treatment comparisons with the ANOVA results. Where these results are referred to, they are called "non-replicated treatments." Frequency tables were used to summarize the categorical variables (crop tree vigour and competitive status). Regression analysis was used to examine individual tree responses to neighbourhood vegetation abundance, and scattergrams were used to identify competition thresholds for conifer stem diameter. All statistical analyses were performed using SAS for Windows, version 6.10 (SAS Institute, Inc. 1996).

Analysis of variance

The distribution of residuals and the tests for normality showed that transformations were generally not necessary for the variables tested. Data were analyzed separately by measurement year and treatment cell using one-way ANOVA with a randomized complete block design ($n = 3$ or 4 for each treatment cell and each replicate in the treatment cell is the mean of ≤ 36 subplot measurements). Sites were considered replicates in a treatment cell if they were comparable in terms of vegetation complex, brushing treatment, ecosystem, and conifer crop species. Differences in history among replicate sites were of secondary importance to comparability in vegetation complex at the time of treatment. In some cases, sites from adjacent biogeoclimatic zones were combined in a single treatment cell for ANOVA, but the sites were carefully examined to ensure that they were similar in vegetation composition and physiographic features. In a few cases, sites were dropped from treatment cells because the vegetation complex did not closely resemble that of other sites in the cell.

Differences between brushing treatment and control means were considered statistically significant at $\alpha = 0.10$. An α level of 0.10 was chosen because it allowed identification of early responses to treatments, which otherwise may not have been detected because of the high variability characteristic of such ecological data. Other vegetation management studies have frequently shown that the significance of differences following treatment increases with time. However, this choice of α level comes at the expense of increased probability of committing a Type I error (finding a treatment effect that does not exist), which must be recognized by the reader. The degrees of freedom, expected mean squares, and F statistics of the ANOVA are shown in Table 4. The standard error of the treatment mean $\bar{y}$ was calculated as $sg = \sqrt{MSE/n}$ where $s_{\bar{y}}$ MSE = Mean Square Error and n = number of replicates (Peterson 1985). The confidence interval estimate of the mean difference between the treatment (T) and control (C) can be calculated as $((y_t - y_c) \pm \sqrt{2MSE/n})$, where t_α has (n-1)(p-1) degrees of freedom and n = number of replicates and p = number of treatments.

Conifer variables tested using one-way ANOVA were total height, leader length, stem diameter, stem diameter increment, and height:diameter ratio. Vegetation variables tested were modal height and percent cover of all vegetation, broadleaf trees, shrubs, herbs, and each target species. Density of broadleaves (stems/ha) was also compared between the brushing treatment and control. Treatment efficacy variables that were tested for target woody stems were total height, current year's growth, number of sprouts, and Expert Committee on Weeds rating.

Interpretation of ANOVA results was enhanced with the use of frequency diagrams that compared stem diameter and height distributions between the brushing treatment and control. In construction of the frequency diagrams, data for each site within a particular ANOVA were standardized to a mean of zero and a standard deviation (s.d.) of 1 regardless of whether the data came from the treatment or the control. This removes site effects from the frequency distribution, while allowing treatment effects to be displayed. For each brushing treatment and control, the frequency of trees over all replicate sites was presented for 0.5 unit standardized diameter or height classes, up to four classes from the mean. Frequency diagrams comparing the brushing treatment and control were constructed for the pre-treatment measurement, as well as each post-treatment measurement year. Qualitative interpretations were made of changes in the diameter and height distributions as a result of brushing treatments.

Regression analysis

Linear and nonlinear regression analyses were used to examine site-specific relationships between crop tree performance and the abundance of surrounding vegetation, which were measured in each tree-centred subplot in the treatment and control (n = 72 for each site). The most recent measurements were used in the analyses. The crop tree response variable used was stem diameter. Competition studies have frequently shown that stem diameter is the most sensitive measure of crop tree response to interspecific competition (e.g., Simard 1990a; Wagner and Radosevich 1991; Simard [2001, in review]). The vegetation abundance measures used were percent cover, modal height, and density of broadleaf trees in stems per hectare (*Mixed Broadleaf-Shrub* and *Aspen* complexes only). Several studies have found good correlations between crop tree stem diameter and interspecific competition indices based on percent cover (Wagner and Radosevich 1991; Wagner and Radosevich 1998), density (Simard 1990a; Newton and Jollife 1998), and the competition index, CRH (Brand 1986; Comeau et al. 1993). Therefore, this study used three groups of competition indices based on percent cover, broadleaf density, and CRH. CRH was defined as:

$$CRH = (C * R)/H$$

where C was percent cover of the dominant vegetation species or species group, R was the modal

TABLE 4 *Analysis of variance (ANOVA) table for individual PROBE treatment cells*

Source of variation	Factor type	Level	Degrees of freedom	MS	Expected F-test (df)
Treatment	fixed	k = 2	k - 1 = 1	MST	MST/MSE (1,2)
Replicate (block)	random	n = 3[a]	n - 1 = 2	MSB	MSB/MSE (2,2)
Error			(n - 1)(k - 1) = 2	MSE	
Total			nk - 1 = 5		

[a] In some treatment cells n = 4

height of the dominant vegetation species or species group, and H was total height of the crop tree. The CRH indices calculated for each complex were based on certain dominant species and species groups that had been shown in earlier studies to have the most important competitive effects on target crop trees, and also were the main targets of operational brushing treatments. This approach contrasts with some other studies where all species or species groups were summed into a single CRH index (e.g., Comeau et al. 1993). The dominant species and species groups used in calculating CRH for each complex were:

- fireweed in the *Fireweed* Complex
- herbs in the *Fern* Complex
- shrubs in the *Mixed Shrub* Complex
- shrubs in the *Ericaceous Shrub* Complex
- herbs in the *Subalpine Herb* Complex
- alder in the *Dry Alder* Complex
- alder in the *Wet Alder* Complex
- broadleaves in the *Aspen* Complex
- broadleaves in the *Mixed Broadleaf-Shrub* Complex
- willow in the *Willow* Complex
- pinegrass in the *Pinegrass* Complex

One linear and one non-linear model were tested. The linear equation takes the form:

$$Y = a + bX$$

where Y is crop tree stem diameter, X is percent cover, broadleaf density, or CRH of the dominant species or species group, a is stem diameter (intercept) at zero cover, density, or CRH, and b is the slope of the relationship. The non-linear model tested was the exponential decay function. It was tested on only one example site for each treatment cell to determine whether the non-linear model improved the data fit over the linear model of stem diameter versus CRH. The non-linear equation takes the form:

$$Y = ae^{-bX} \qquad [3]$$

where Y is crop tree stem diameter, X is CRH of the dominant species or species group, a is the y-intercept, and b is the shape parameter. The regression models were evaluated based on their significance (p-value) and coefficient of determination (adjusted r^2 value).

Competition thresholds

Competition thresholds were determined for each site from scattergrams of stem diameter versus one of the three measures of competition (percent cover, broadleaf density, and CRH). Competition thresholds were identified on the assumption that competition is a constraint of target crop tree performance (Burton 1993). The constraint perspective is supported by many studies that show high variability in crop tree performance across low to intermediate neighbourhood abundance, and where regression relationships generally have low coefficients of determination. Those trees experiencing high competition have competition as a limiting factor, whereas trees experiencing low and medium levels of competition appear to be limited primarily by other factors.

For each scattergram, a ceiling function that described the upper boundary of the scattergram, and enveloped at least 95% of the observations, was used to identify competition thresholds (after Wagner et al. 1989; Burton 1993). Ceiling functions were defined using neighbourhood data (percent cover, broadleaf stem density, and CRH) collected from the most recent measurement year, taking into account treatment responses. Using these graphs, threshold competition levels were identified, below which target conifer stem diameter was independent of decreasing neighbourhood abundance, and above which diameter declined sharply in response to increasing neighbourhood abundance (i.e., the level at which competition became the primary constraint on stem diameter) (Figure 4).

Competition thresholds and regression coefficients were tabulated for each site in each complex in order to illustrate their between-site variability (e.g., Table 13). Competition thresholds were also averaged among the replicate sites for each vegetation complex-ecosystem-conifer-tree species combination, regardless of brushing treatment. In some cases, sites not used in ANOVA were included in mean and standard error calculations. As a result, threshold means included between one and 10 replicate sites. Discussion of threshold results focused on mean threshold values and their variability, rather than on individual sites. It is recognized that competition thresholds vary on a site-specific basis according to ecosystem, site quality, species composition, stand age, disease or insect problems, and other factors (Burton 1993; Simard [2001, in review]). However, there was insufficient replication in this study to examine the effects of these individual factors on threshold variation.

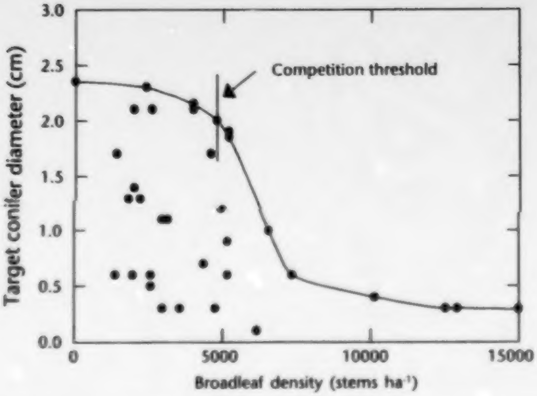

FIGURE 4 *Hypothetical relationship between crop tree stem diameter and interspecific competition. The maximum-response (or competition) threshold is the competition level at which tree diameter becomes constrained by interspecific competition.*

SECTION 4

Fireweed Complex

ABSTRACT

The effects of manual cutting, glyphosate, and grazing on conifer seedlings and the *Fireweed* Complex were examined on circum-mesic sites in the ICH and ESSF zones for 1–5 years.

Manual cutting—Single manual cutting treatments had a short-lived effect on abundance of the *Fireweed* Complex, and did not significantly affect survival or growth of Engelmann spruce and lodgepole pine seedlings in either the ICH or ESSF zones after 3–5 years. Cutting did not reduce height or cover of fireweed, the herb layer, or overall vegetation, even in the first year after treatment, and had only a minor effect on the shrub layer. Species richness and diversity were unaffected by manual cutting.

Glyphosate—Brushing with glyphosate at 1.4–2.1 kg ai/ha reduced abundance of the ESSF *Fireweed* Complex, but had only minor effects on Engelmann spruce seedling growth. After 5 years, survival was good (average 91%) in both the treatment and the control, and there were no differences in seedling stem diameter, diameter increment, height, or leader height. Crop tree height:diameter ratio was significantly lower in the treatment than the control (41.9 versus 46.9). Fireweed height and cover were reduced for at least 5 years by the glyphosate treatment, and so was overall vegetation cover. Height and cover of the herb layer were reduced for only a single year. Species richness and diversity were not affected by the glyphosate treatment.

Sheep and cattle grazing—A single grazing pass by sheep or cattle had little effect on the *Fireweed* Complex in the ESSF zone. Height of the herb layer was significantly reduced 1 year after grazing, but abundances of fireweed and overall vegetation were unaffected. There were no improvements in Engelmann spruce seedling survival or growth as a result of grazing after 5 years, but overall seedling vigour was considerably reduced due to cattle trampling in one of the treated plots. Grazing had no effect on species richness or diversity.

Competition thresholds averaged 36, 46, and 40% cover, and 49, 60, and 49 CRH for Engelmann spruce in the ESSF zone, Engelmann spruce in the ICH zone, and lodgepole pine in the ICH zone, respectively. These thresholds, as well as other competition and light studies, suggest that adequate growth rates of spruce and pine may be maintained under moderate levels of fireweed.

Our early results suggest that brushing the *Fireweed* Complex is unlikely to contribute to the achievement of free-growing unless vegetation is threatening the survival of newly planted seedlings. Otherwise, seedlings growing on circum-mesic sites are achieving minimum height requirements and outgrowing the fireweed canopy within the free-growing window, regardless of whether or not they are brushed.

Description of the *Fireweed* Complex

When the *Fireweed* Complex first invades newly disturbed sites, it is composed of relatively pure stands of fireweed (*Epilobium angustifolium*). As time passes since disturbance, however, it may include minor components of grasses, ferns such as lady fern (*Athyrium filix-femina*) and oak fern (*Gymnocarpium dryopteris*), and various shrub species such as thimbleberry (*Rubus parviflorus*), red raspberry (*Rubus idaeus*), Sitka alder (*Alnus viridis*), and willow (*Salix* spp.) (Boateng and Comeau 1997b) (Figure 5).

The *Fireweed* Complex occurs in virtually all biogeoclimatic zones of British Columbia, as long as moisture is sufficient (McLean 1979). It tolerates a wide range of environmental conditions, but grows best on mesic and subhygric sites under full light conditions (Haeussler et al. 1990). The *Fireweed* Complex is common in the ICH, ESSF, and MS zones of the southern interior, and to a lesser extent in the IDF zone.

Development of the *Fireweed* Complex

The *Fireweed* Complex is likely to be present on moist, cool sites following any type of disturbance that increases light levels and disturbs the forest floor, particularly if mineral soil is exposed. Therefore, sites that are summer-logged are more likely to develop a vigorous fireweed community than sites that are winter-logged (Haeussler et al. 1990).

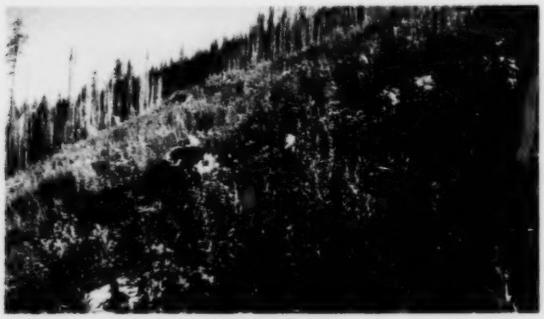

FIGURE 5 *The* Fireweed *Complex prior to manual cutting treatment at Bugle Creek (Site 108) in the ESSFwc1 variant in the Arrow Forest District. Photo credit: JMJ Holdings Inc.*

Fireweed is an extremely successful colonizer of newly disturbed sites because of its vigorous reproductive strategies, both sexual and vegetative. It competes poorly with established vegetation, however, and will not colonize sites that are already fully occupied (Mosquin 1966; Haeussler et al. 1990, citing Watson et al. 1980). A single fireweed stem can produce 20 000–80 000 lightweight, plumed seeds (Myerscough 1980), which, once airborne, can travel hundreds of kilometres (Solbreck and Andersson 1987). Following germination, fireweed plants grow rapidly, and can reach their full height of 1–3 m and flower in a single season (Myerscough 1980; Haeussler et al. 1990). Once a site is colonized by young fireweed, the population expands mainly by means of a perennial rhizome system that spreads horizontally outward from the parent plant, producing new shoots from buds along its length.

Although fireweed colonies are capable of living for decades, their longevity depends on rates of succession. As a canopy of shrubs and conifers develops, fireweed dies out or persists at only low densities (Mosquin 1966; Haeussler et al. 1990). In the southern interior of British Columbia, fireweed may overtop slow-growing seedlings for 10 or more years (Haeussler et al. 1990). On cedar-hemlock sites, it reaches peak abundance about 5 years after disturbance (Boateng and Comeau 1997b).

Interactions with Conifer Seedlings

The *Fireweed* Complex is one of the early seral plant communities identified as a serious competitor to conifer seedlings in the southern interior of British Columbia (Kimmins and Comeau 1990). Fireweed affects seedling performance mainly by reducing the availability of light, and once seedlings have become spindly, they are easily damaged by snow and vegetation press. A dense fireweed canopy can reduce light levels to less than 5% of full sunlight (Comeau 1988), and can do so earlier in the growing season than other competing species, such as thimbleberry (DeLong 1991). In addition to reducing light availability, dense vegetation also slows and reduces soil warming (Spittlehouse and Stathers 1990; Balisky and Burton 1993), which contributes to poor seedling performance at higher elevations. In British Columbia, competition by the *Fireweed* Complex for soil water and nutrients appears to be minor in comparison with competition for light.

Competition thresholds for fireweed have previously not been well defined, but Comeau et al. (1993) suggest that either competition indices or measurements of light transmittance are potentially useful. These authors found that 63% of the variation in Engelmann spruce growth on a fireweed-dominated site could be explained by late-July light transmittance. Lindeburgh (1995) reported that even moderate levels of fireweed competition reduced seedling growth, whereas survival tended to be affected mainly on subhygric to hygric sites that were associated with lower slope position, probably because competition was more severe.

The incidence of insect damage to conifer seedlings may increase as a result of vegetation control in the *Fireweed* Complex. Following brushing, Lindeburgh et al. (1994) found a higher incidence of spruce gall aphid (*Adelges cooleyii*) on Engelmann spruce and Douglas-fir seedlings, and a higher incidence of spruce leader weevil (*Pissodes strobi*) on spruce. Greater weevil attack may have occurred because seedlings were more visually obvious above the fireweed, their leaders were larger and more attractive for oviposition, and/or the environment may have changed in favour of overwintering adults (Gara et al. 1971).

Importance to Wildlife and Range

Fireweed is of low to moderate importance to wildlife in British Columbia. It is browsed to some extent in the summer by deer, moose, and elk (Kufeld 1973; McLean 1979; Haeussler et al. 1990), and by snowshoe hares in the spring (Wolff 1978). However, the *Fireweed* Complex likely increases in importance to wildlife as shrubs become established. The berries of thimbleberry and red raspberry are favoured by many wildlife species (Haeussler et al. 1990), and tall shrubs such as alder and willow provide cover for large mammals. Fireweed flowers are also utilized by bees for honey production.

Cattle have low preference for fireweed, but find it most palatable while it is flowering. It may be part of their diet from spring until fall frost (McLean 1979). Fireweed, especially when young shoots are present, is a preferred species for sheep (Newsome 1996).

Common Brushing Treatments in the *Fireweed* Complex

In the southern interior British Columbia, the *Fireweed* Complex is generally brushed manually or with glyphosate, although grazing is also a common treatment in some areas (Table 5). Decisions about whether to brush the *Fireweed* Complex are generally made on the basis of visual estimates of competition levels. However, field staff reportedly have difficulty identifying a need for seedling release at lower levels of fireweed abundance, even though seedlings could be receiving as little as 30% of full midsummer sunlight (Comeau et al. 1993).

TABLE 5 *Common brushing treatments applied to the* Fireweed Complex *in the southern interior of B.C.*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tools	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Reduce light competition 2. Reduce snow- and vegetation-press	Mid- to late-June to reduce light competition and after the first frost to reduce vegetation press[b]	2–3	1. Weed whacker 2. Motorized brush saw 3. Machete	$511 $538 $511	Repeat treatments are costly
Glyphosate (1.4–2.1 kg ai/ha)	1. Reduce light competition 2. Reduce snow- and vegetation-press 3. Increase soil warming	Mid-July to mid-August[c]	1	1. Backpack sprayer 2. Fixed-wing plane or helicopter (aerial)	$700 $311	Cannot apply near waterways
Grazing	1. Reduce light competition 2. Reduce snow- and vegetation-press	As soon as possible after seedlings harden off[d]	2–3[d]	1. Sheep 2. Cattle	$248	Potential for conifer damage if flocks or herds are not carefully managed

[a] Based on average costs in the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)

[b] J. Wright, pers. comm., 1999

[c] Lloyd and Heineman (1994a)

[d] Newsome et al. (1995)

The responses of Engelmann spruce, lodgepole pine, and vegetation to manual brushing of the *Fireweed* Complex in the ESSF and ICH zones are described in this section. The responses of Engelmann spruce and vegetation to foliar glyphosate treatment of the ESSF *Fireweed* Complex are also presented.

Manual Cutting

This section describes third-year Engelmann spruce and vegetation responses to manual cutting of the *Fireweed* Complex in the ESSF zone and upper portions of the ICH zone (n = 4). Spruce were 2–4 years old at the time of treatment. It also describes fifth-year responses of lodgepole pine and vegetation to manual cutting of the *Fireweed* Complex in the ICH zone (n = 3). Pine were 1–3 years old at the time of treatment.

Engelmann spruce in the ESSF zone and higher-elevation ICH zone

We have third-year results demonstrating the effects of manual brushing of the *Fireweed* Complex in the ESSF zone and higher-elevation ICH zone on vegetation and Engelmann spruce seedlings.

Description of the study sites and treatments

This treatment cell includes four study sites: three in the Nelson Forest Region and one in the Kamloops Forest Region. The Bugle Creek and Murphy Creek sites are in the Arrow District, 20 and 50 km southwest of Castlegar, respectively. The O'Brien Creek site is 100 km north of Kaslo in the Kootenay Lake District, and the Craigellachie site is 15 km north of Malakwa in the Salmon Arm District. Physiographic features, site histories, and conifer and vegetation characteristics for each site are summarized in Table 6. Two of the sites are located in the Columbia Wet Cold ESSF variant (ESSFwc1), one in the Wells Gray Wet Cool ICH variant (ICHwk1), and one in the Shuswap Moist Warm ICH variant (ICHmw2). ESSF and ICH zone sites were grouped together in this treatment cell because the two ICH sites were close in elevation to the boundary of the ESSF zone and had similar vegetation and physiography to the ESSF sites.

The study sites range in elevation from 1160 to 1680 m, and have moderate slopes (25–50%) and variable aspects (east, west, south). Two sites are in lower slope positions (one mesic and one subhygric) and two are at mid-slope (mesic). Soils are loamy-textured (silt-loam to loam) Brunisols and Podzols.

Two of the sites (Bugle Creek and O'Brien Creek) were clearcut in 1988–1989, broadcast burned within 1 year of harvest, and planted with spruce within 2 years of burning. A third site (Murphy Creek) was clearcut in 1987 and spot-burned in 1989. The fourth site (Craigellachie) had a somewhat different site history. It was clearcut in 1981 and did not receive any further treatment until it was mechanically prepared in 1989. All four sites were planted within 2 years of site preparation. Brushing took place (and PROBE was initiated) 3–6 years after site preparation, at which time seedlings were 2–4 years old. At that time, total conifer stocking on the three sites ranged from 1022 to 1472 stems/ha, of which 873–1136 stems/ha were well spaced.

Immediately prior to brushing, fireweed dominated the vegetation on all four sites, with mean cover values ranging from 27 to 63% and mean heights from 73 to 139 cm. On two of the sites, red raspberry was also common. Vegetation overtopped seedlings on all sites. Vegetation was cut in a 0.5–1.0 m radius around target spruce seedlings on the four sites, on dates in early July through October (Table 7). The objectives of brushing were primarily to reduce vegetation press and secondarily to increase the transmittance of light to seedlings. Three sites received only a single manual cutting treatment, and one received treatments 2 years in a row.

Conifer response

Survival and vigour Three years after manual cutting, survival of the 5- to 7-year-old spruce seedlings (2–4 years old at the time of treatment) was excellent in both the treatment and control (average 96%, p = 0.29) (Table 8). A variety of factors were responsible for the small amount of mortality that did occur, but only one seedling across all four sites was recorded as dying from competing vegetation.

Manual brushing did not affect Engelmann

TABLE 6 *Characteristics and history of the four replicate study sites where the ESSF/ICH* Fireweed *Complex was manually cut in Engelmann spruce plantations prior to treatment*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (years)	Origin[b]	Stock	Age[c] (years)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Craigellachie PROBE 56 Salmon Arm District	ICHwk1 01 (mesic)	1160	E 45%	Podzol/ loam	Clearcut 1981 MSP 1989	14	6	2	P 1990/91	PSB 313A PSB 415B	4	63 (16)	Fireweed cover: 27 (15) Fireweed height: 73 (13) Raspberry cover: 12 (12) Raspberry height: 40 (13)	1281	873
Bugle Creek PROBE 108 Arrow District	ESSFwc1 04 (subhygric)	1680	W 50%	Podzol/ loam	Clearcut 1988 Burned 1988	6	4	2	P 1990	PSB 313	2	24 (6)	Fireweed cover: 63 (17) Fireweed height: 125 (14)	1022	919
Murphy Creek PROBE 112 Arrow District	ICHmw2 01 (mesic)	1370	S 25%	Brunisol/ silt loam	Clearcut 1987 Spot burned 1989	5	3	0	P 1989	PSB 313B	3	42 (11)	Fireweed cover: 58 (16) Fireweed height: 139 (22)	1531	972
O'Brien Creek PROBE 124 Kootenay Lake District	ESSFwc1 01 (mesic)	1200	W 35%	Brunisol/ silt loam	Clearcut 1988/89 Burned 1990	4	3	1	P 1991	PSB 313B	2	59 (13)	Fireweed cover: 32 (24) Fireweed height: 104 (28) Lady fern cover: 24 (26) Lady fern height: 64 (23) Raspberry cover: 13 (14) Raspberry height: 59 (23)	1472	1136

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P=planted; N=natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 7 *A description of manual cutting treatments applied to the four replicate study sites to release Engelmann spruce seedlings growing in the ESSF/ICH* Fireweed *Complex*

Site	Initial treatment date	Treatment radius	Treatment tool	Repeat treatment
Craigellachie	Late August 1995	1.0 m	Brush saw	None
Bugle Creek	Mid-August 1992	0.7 m	Weed whacker	None
Murphy Creek	October 1992	0.5 m	Brush saw	None
O'Brien Creek	July 5, 1993	1.0 m	Brush saw	June 24, 1994

TABLE 8 *Survival and growth responses of Engelmann spruce seedlings to manual cutting in the ESSF/ICH* Fireweed *Complex*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	98	99	1.235	0.72
3 yr post-treatment	94	97	1.196	0.29
Stem diameter (cm)				
Pre-treatment	0.93	0.96	0.065	0.78
1 yr post-treatment	1.18	1.28	0.104	0.55
3 yr post-treatment	2.14	2.28	0.152	0.57
Diameter increment (cm)				
1 yr post-treatment	0.27	0.33	0.055	0.47
3 yr post-treatment	0.41	0.41	0.023	0.96
Height (cm)				
Pre-treatment	46.7	47.6	0.868	0.54
1 yr post-treatment	59.1	62.1	1.389	0.22
3 yr post-treatment	94.0	96.2	2.982	0.63
Leader length (cm)				
Pre-treatment	12.0	11.4	0.731	0.60
1 yr post-treatment	11.3	12.7	0.844	0.31
3 yr post-treatment	16.1	14.7	0.992	0.40
Height: diameter ratio				
Pre-treatment	49.9	50.8	2.371	0.80
1 yr post-treatment	51.4	50.1	3.164	0.78
3 yr post-treatment	45.1	44.5	1.397	0.81

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

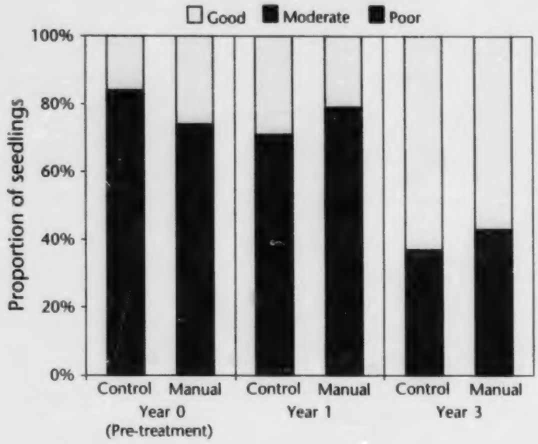

FIGURE 6 *Comparison of Engelmann spruce vigour between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF/ICH* Fireweed *Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

spruce vigour (Figure 6), which improved in both the treatment and control during the 3-year monitoring period. Prior to cutting, an average of 67% of seedlings were of moderate vigour, 12% were poor, and 21% were good. The proportion of seedlings of good vigour increased during the 3-year monitoring period (to 63% in the control and 57% in the manual cutting treatment), while the proportion of poor-vigour seedlings remained constant in the treatment and dropped slightly in the control.

Growth Three years after manual cutting of the *Fireweed* Complex, there were no significant effects on spruce height, leader length, stem diameter, stem diameter increment, or height:diameter ratio ($p>0.10$) (Table 8, Figure 7). Prior to manual

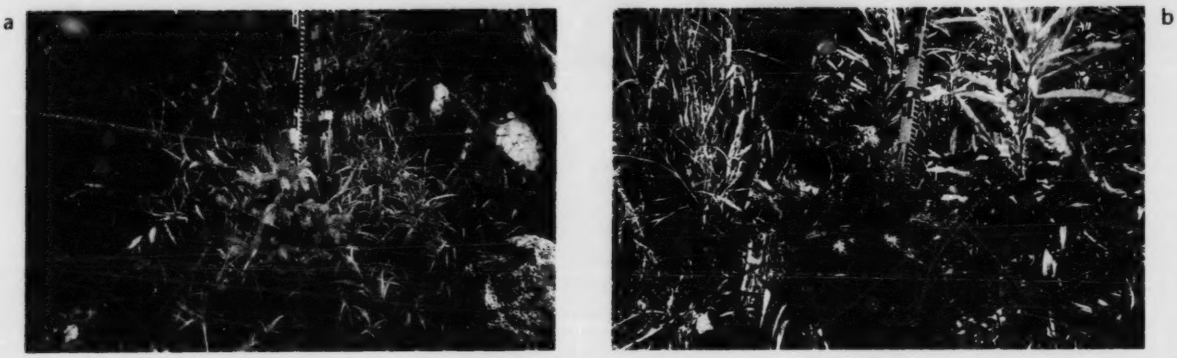

FIGURE 7 *Engelmann spruce seedlings in the (a) treatment and (b) control 5 years following manual cutting at Bugle Creek. The treatment had no effect on spruce performance.* Note: *Although the photo shows fifth-year responses, we report statistical results for only 3 years because not all replicate sites had been measured for 5 years. Photo credit: JMJ Holdings Inc.*

cutting, seedlings averaged 47.2 cm tall in the control and manual cutting treatment (p = 0.54). Three years later they averaged 95.1 cm tall (p = 0.63), with 15.4-cm leaders (p = 0.40). Stem diameter more than doubled within the 3-year measurement period, from 0.95 cm pre-treatment to 2.21 cm in year 3, but there were no differences between the treatment and control (p = 0.57). There were no significant differences between the treatment and control in height:diameter ratio, which averaged 50.4 prior to cutting (p = 0.80) and 44.8 in year 3 (p = 0.81).

Spruce diameter and height distributions were similar in the brushing treatment and control before treatment, and remained similar through 3 years post-treatment (Figures 8 and 9). Height and diameter distributions became increasingly normal as time passed, and frequency counts in the different classes varied little between the treatment and control. The distributions agree with ANOVA results that manual cutting had no effect on spruce height or diameter growth.

Competitive status Manual treatment of the *Fireweed* Complex had no lasting effect on the competitive status of spruce seedlings (Figure 10), but the proportion of seedlings that were above surrounding vegetation was increasing gradually in both the treatment and control. Prior to treatment, the majority (average 97%) of seedlings were either overtopped or threatened by vegetation. Three years later, an average 19% of seedlings were free of vegetation, with the transition taking place equally in the treatment and control. As of year 3, an average 66% of seedlings continued to be overtopped by the *Fireweed* Complex, but seedling height (95.1 cm) was approaching that of the approximately 1-m-tall vegetation canopy.

Plant community response

Abundance Fireweed was the primary brushing target in this study, but manual cutting had no effect on its height or cover after either 1 or 3 years (p>0.10) (Table 9, Figure 11). Neither were there any differences in height and cover of all vegetation or the herb layer as a result of treatment. Shrub cover in the treatment and control were similar in year 1 (p>0.10), but, in year 3, cover in the control had increased relative to the treatment (23.9% in the control versus 18.6% in the treatment, p = 0.04) (Figure 12). It is unclear whether this difference was related to the cutting treatment. There were pre-treatment differences in shrub height between the treatment and control, which disappeared in years 1 and 3.

Richness and diversity of individual species and vegetation structural groups Manual cutting of the *Fireweed* Complex had no effect on either species richness or species diversity (p>0.10) (Table 10). Prior to manual cutting, an average of 31 vascular plant species were present, and 3 years later there was an average of 38 species, but the increase occurred equally in the treatment and the control. Diversity indices fluctuated somewhat, being slightly higher in the first-year assessment than in the pre-treatment or third-year assessments, but again, the changes occurred similarly in the treatment and the control.

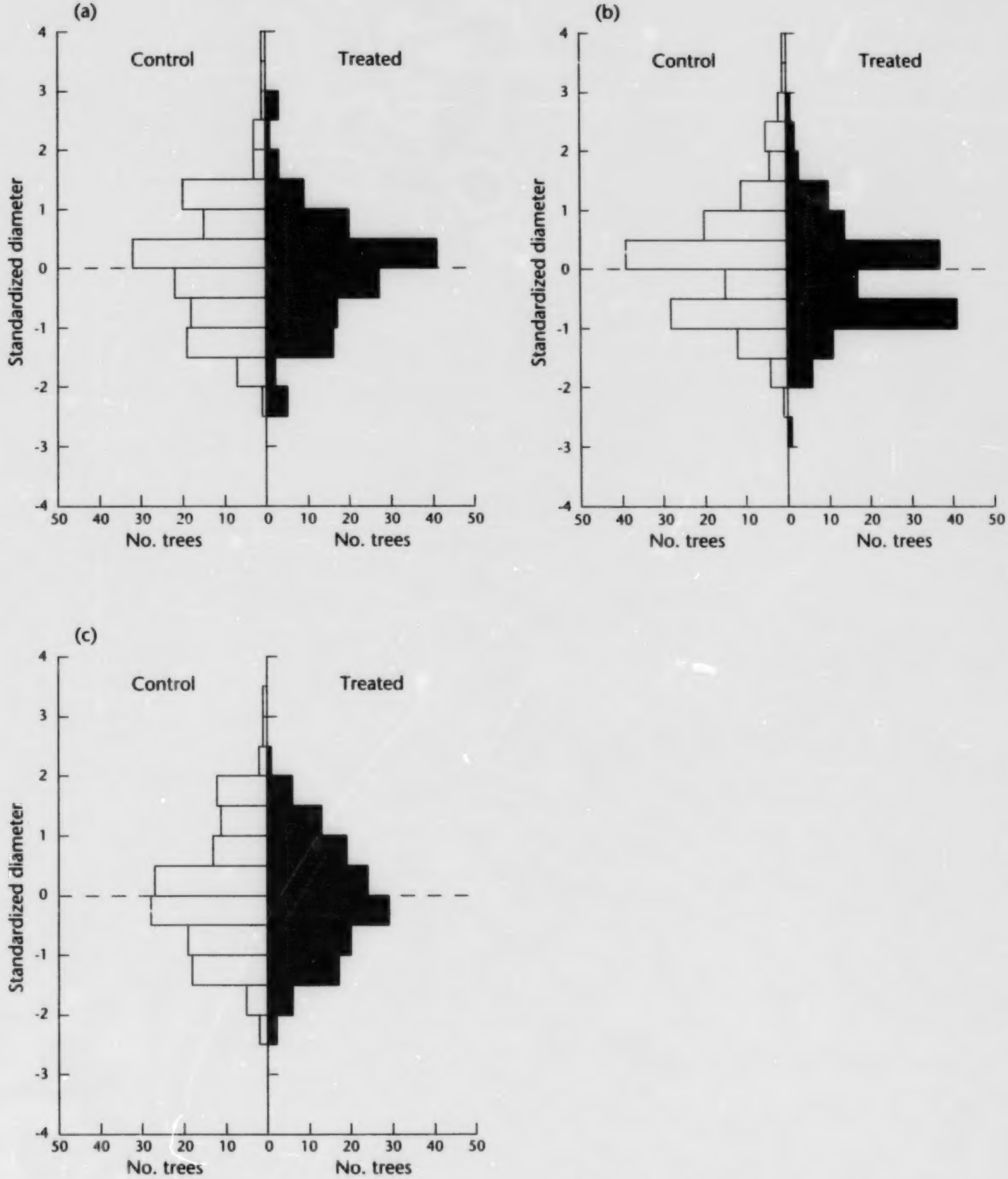

FIGURE 8 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 4 for the control and treatment combined) for Engelmann spruce in the ESSF/ICH* Fireweed Complex *before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

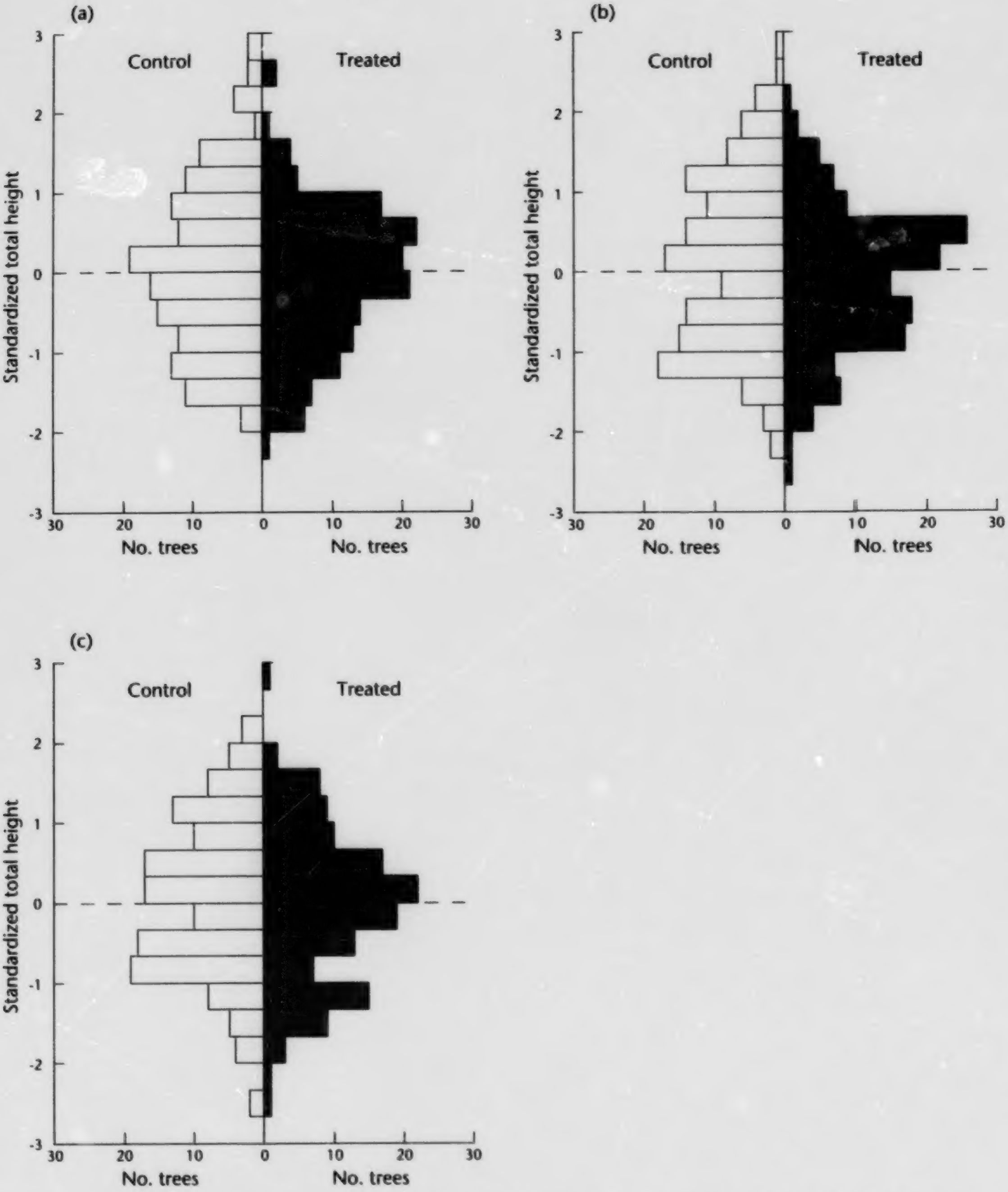

FIGURE 9 *Frequency of control and treated trees in standardized total height classes ($\mu = 0$; s.d. = 1; $n = 4$ for the control and treatment combined) for Engelmann spruce in the ESSF/ICH* Fireweed Complex *before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

TABLE 9 *Cover and height of vegetation in the ESSF/ICH Fireweed Complex before and after manual cutting in Engelmann spruce plantations*

Response variable	Means Manual cutting	 Control	Standard error	p-value
Fireweed				
Cover (%)				
Pre-treatment	44.9	44.7	3.228	0.98
1 yr post-treatment	44.7	45.8	3.720	0.84
3 yr post-treatment	45.8	42.2	5.237	0.66
Height (cm)				
Pre-treatment	115.0	105.5	3.561	0.16
1 yr post-treatment	99.1	96.9	5.348	0.80
3 yr post-treatment	104.8	101.4	3.882	0.58
All vegetation				
Cover (%)				
Pre-treatment	76.4	75.9	5.687	0.95
1 yr post-treatment	77.7	79.9	1.431	0.35
3 yr post-treatment	80.7	74.0	2.938	0.21
Height (cm)				
Pre-treatment	99.1	90.2	3.606	0.18
1 yr post-treatment	79.4	92.1	10.901	0.47
3 yr post-treatment	95.2	97.8	5.792	0.77
Herbs				
Cover (%)				
Pre-treatment	67.5	64.8	3.629	0.63
1 yr post-treatment	69.6	71.5	2.774	0.67
3 yr post-treatment	67.9	59.9	3.182	0.17
Height (cm)				
Pre-treatment	99.8	92.9	3.392	0.24
1 yr post-treatment	82.5	86.4	8.769	0.78
3 yr post-treatment	93.5	92.1	5.084	0.86
Shrubs				
Cover (%)				
Pre-treatment	14.2	18.3	4.680	0.58
1 yr post-treatment	13.2	14.5	3.423	0.80
3 yr post-treatment	18.6	23.9	1.095	0.04*
Height (cm)				
Pre-treatment	70.6	53.8	3.954	0.06*
1 yr post-treatment	53.6	59.3	6.818	0.66
3 yr post-treatment	66.9	73.0	4.756	0.87

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 4$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

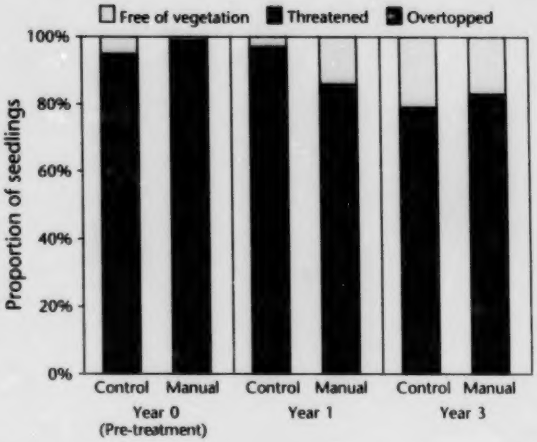

FIGURE 10 *Comparison of Engelmann spruce competitive status between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF/ICH Fireweed Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

FIGURE 11 *The Fireweed Complex 1 year following manual cutting at Bugle Creek. Vegetation was cut in a 0.7-m radius around seedlings, and had recovered to control levels within 1 year of treatment. Photo credit: JMJ Holdings Inc.*

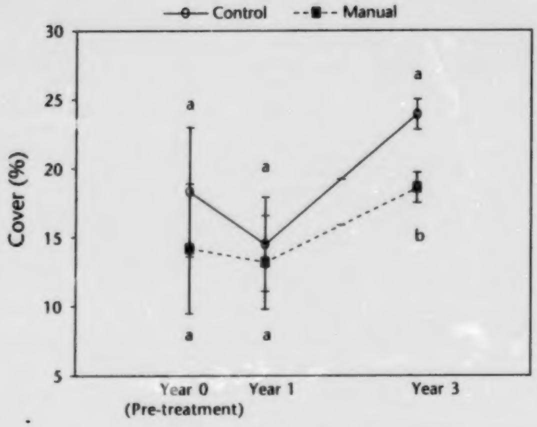

FIGURE 12 *Comparison of mean shrub cover between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF/ICH* Fireweed Complex. *Error bars represent one standard error of the mean $(\bar{y})$ which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

There were no significant differences in the richness or diversity of structural vegetation groups ($p>0.10$) (Table 11).

Manual cutting treatments are prescribed for the *Fireweed* Complex to reduce the abundance of tall herbaceous vegetation in the neighbourhood of conifer seedlings. However, cover estimates for individual species in the eight diversity plots failed to show that that had occurred. Fireweed abundance decreased in the treated plots of two sites, but was unaffected on the other two sites. ANOVA results also showed that manual cutting had no effect on fireweed abundance. Pearly everlasting (*Anaphalis margaritacea*) was the only herb species that tended to change in abundance following manual cutting (Table 12); its cover increased in the treated plots on two of four sites. Shrubs were affected more by the cutting treatment. Abundance of devil's club (*Oplopanax horridus*) decreased in the treatment following cutting on two of four sites, while false-box (*Pachistima myrsinites*) and thimbleberry increased on two of four sites. Berry-producing shrubs such as black huckleberry (*Vaccinium membranaceum*) and red raspberry were common on these sites, but their abundance was not affected by the manual cutting treatment.

TABLE 10 *Richness and diversity of vascular plant species in the ESSF/ICH* Fireweed Complex *before and after manual cutting in Engelmann spruce plantations*

Response variable	Means Manual cutting	 Control	Standard error	p-value
Richness				
Pre-treatment	30.00	31.25	1.168	0.50
1 yr post-treatment	30.50	31.00	2.492	0.90
3 yr post-treatment	37.00	38.50	1.837	0.60
Shannon-Weaver Diversity Index				
Pre-treatment	1.85	1.97	0.088	0.41
1 yr post-treatment	1.96	2.00	0.080	0.80
3 yr post-treatment	1.87	1.91	0.116	0.80
Simpson's Diversity Index				
Pre-treatment	0.71	0.74	0.022	0.31
1 yr post-treatment	0.73	0.74	0.020	0.64
3 yr post-treatment	0.69	0.68	0.034	0.88

The standard error of the overall mean $(\bar{y})$ was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 11 *Richness and diversity of structural vegetation groups in the ESSF/ICH* Fireweed Complex *before and after manual cutting in Engelmann spruce plantations*

Response variable	Means Manual cutting	 Control	Standard error	p-value
Richness				
Pre-treatment	6.00	6.25	0.339	0.64
1 yr post-treatment	5.75	6.00	0.177	0.39
3 yr post-treatment	5.75	6.00	0.177	0.39
Shannon-Weaver Diversity Index				
Pre-treatment	0.94	1.06	0.085	0.39
1 yr post-treatment	0.99	1.02	0.053	0.78
3 yr post-treatment	0.93	0.95	0.086	0.88
Simpson's Diversity Index				
Pre-treatment	0.50	0.57	0.038	0.27
1 yr post-treatment	0.52	0.54	0.026	0.71
3 yr post-treatment	0.47	0.50	0.040	0.70

The standard error of the overall mean $(\bar{y})$ was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 12 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ESSF/ICH* Fireweed *Complex in Engelmann spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Tall shrubs			*Acer glabrum* *Salix* spp.
Short shrubs	*Pachistima myrsinites* *Rubus parviflorus*	*Oplopanax horridus*	*Ribes lacustre* *Rubus idaeus* *Sambucus racemosa* *Vaccinium membranaceum*
Herbs	*Anaphalis margaritacea*		*Actaea rubra* *Athyrium filix-femina* *Carex* spp. *Epilobium ciliatum* Grass spp. *Lupinus sericeus* *Thalictrum occidentalis*

Competition thresholds

Fireweed competition thresholds for Engelmann spruce were derived separately for the ICH and ESSF zones because we hypothesized that spruce tolerance of competition would change with climatic conditions and growth-limiting factors. The threshold information presented below includes all of our ICH or ESSF spruce plantations, regardless of the brushing treatment applied. Consequently, the following analysis includes not only sites that were brushed manually, but also those that were treated with gylphosate, mulch mats, or grazing.

Engelmann spruce in the ICH zone This section summarizes thresholds for ICH spruce plantations where fireweed was brushed using either manual or glyphosate methods (n = 6). The fireweed cover and CRH thresholds for Engelmann spruce diameter growth in the ICH zone were 46 and 60%, respectively, where CRH = (fireweed cover * fireweed modal height)/spruce height (e.g., Figure 13). There was little variation in thresholds among sites, which may be related to the narrow range in stand (2–7 years) and spruce ages (1–4 years) (Table 13). The cover thresholds were generally diffuse and high (i.e., on some sites, equivalent to the maximum localized fireweed cover), whereas the CRH thresholds were generally sharp (e.g., Figure 13).

A small proportion of trees (17–28%) were growing in neighbourhoods above the thresholds, and may therefore benefit from further selective brushing. There was a fairly even proportion of control and treated trees overall both above and below the thresholds. Most treated trees (85–88%) fell below the thresholds, indicating that brushing successfully reduced fireweed abundance below the competition thresholds, at least temporarily. However, only 4–5% of treated trees that occurred below the fireweed thresholds achieved ≥80% of the maximum diameter measured on the site. In addition, both the means ($p>0.10$) (Table 8) and the distributions of spruce diameters across fireweed neighbourhoods (e.g., Figure 13) were similar between the control and manual treatment, indicating that spruce diameter had not responded to the short-term fireweed reductions. An exception was found on one of the glyphosate-treated sites, however, where the largest-diameter trees were treated trees that fell below the competition thresholds. This result suggests that glyphosate treatments have the potential to improve spruce growth in the ICH *Fireweed* Complex.

Linear regressions of spruce diameter versus fireweed cover were significant ($p<0.10$) for four of the six sites (Table 13). Of the significant regressions, coefficients of determination were very low

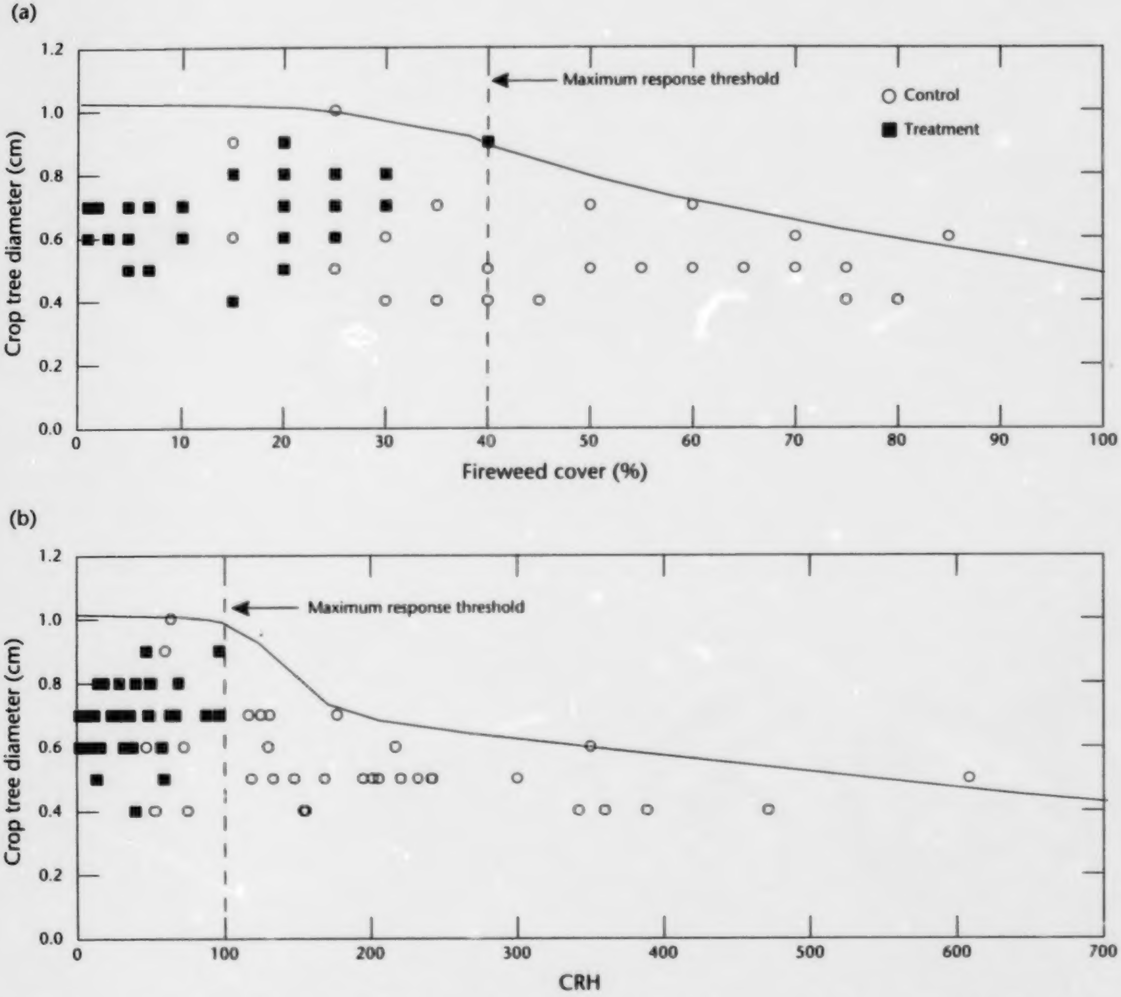

FIGURE 13 *Relationship between stem diameter of Engelmann spruce growing amongst the ICH* Fireweed *Complex and (a) fireweed cover or (b) CRH, where CRH = (fireweed cover * fireweed modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 79 (n = 68). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover and CRH values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

(adjusted r^2 0.04–0.14) and the slopes were negative but shallow (β_1 -0.002 to -0.013). These results reflect the wide variability in spruce diameter across the broad range in localized fireweed covers (0–90%) that occurred in all plantations. Similarly, linear regressions between spruce diameter and CRH were significant ($p<0.10$) for all of the seven sites, but their coefficients of determination were low (adjusted r^2 0.03–0.24) and the slopes were shallow (β_1 -0.001 to -0.026). Fitting a negative exponential function to the diameter-CRH relationship on one site marginally improved the adjusted r^2 from 0.17 to 0.20. The low adjusted r^2 values and shallow, negative slopes of the regressions suggest

TABLE 13 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Engelmann spruce stem diameter from the competition indices, fireweed cover and CRH, in the Fireweed Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from fireweed cover[a]	Adjusted r^2 for linear regression predicting diameter from fireweed cover	p-value for linear regression predicting diameter from fireweed cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
56	72	4	40	$y = 2.312 - 0.009\,x$	0.04	0.05	38	$y = 2.509 - 0.011\,x$	0.17	0.00	$y = 2.619\,e^{(-0.006 * x)}$	0.20
59	70	1	57	$y = 1.138 + 0.004\,x$	0.01	0.21	66	$y = 1.356 - 0.002\,x$	0.03	0.08		
63	71	1	70	$y = 1.529 - 0.002\,x$	0.00	0.31	86	$y = 1.554 - 0.002\,x$	0.04	0.05		
79	68	0	40	$y = 0.694 - 0.002\,x$	0.14	0.00	100	$y = 0.683 - 0.001\,x$	0.24	0.00		
82	62	4	30	$y = 3.264 - 0.017\,x$	0.03	0.07	18	$y = 3.297 - 0.026\,x$	0.12	0.00		
112	67	3	40	$y = 3.414 - 0.013\,x$	0.09	0.01	50	$y = 3.661 - 0.016\,x$	0.24	0.00		
mean (s.e.)			46 (6)				60 (12)					

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is fireweed cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (fireweed cover * fireweed modal height)/spruce total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

that fireweed competition on these sites was of low importance and intensity to the plantations as a whole.

Engelmann spruce in the ESSF zone Fireweed competition thresholds for Engelmann spruce in the ESSF zone were derived using all ESSF spruce plantations regardless of the brushing treatment applied. As a result, this section summarizes thresholds for ESSF spruce plantations where fireweed was brushed using either manual, glyphosate, grazing, or mulch mat methods (n = 12). The fireweed cover and CRH thresholds for Engelmann spruce diameter growth in the ESSF zone were 36 and 49%, respectively, where CRH = (fireweed cover * fireweed modal height)/spruce height. There was little variation in thresholds among sites, even though the ranges in stand (3–15 years) and spruce ages (0–5 years) were fairly wide (Table 14). The cover thresholds were generally diffuse and the CRH thresholds were sharp, but above both thresholds there was a consistent decline in spruce diameter (e.g., Figure 14).

A moderate proportion of trees (38–54%) were growing in neighbourhoods above the thresholds, and may therefore benefit from further selective brushing. Most trees above the thresholds were control trees (59–61%), whereas most below the thresholds were treated trees (63–69%). Most treated trees (60–73%) fell below the thresholds, indicating that brushing was moderately successful at reducing fireweed abundance below the competition thresholds, at least temporarily. However, only 3% of treated trees that occurred below the fireweed thresholds achieved ≥80% of the maximum diameter measured on the site. In addition, both the means ($p>0.10$) (Tables 8, 25, and 32) and the distributions of spruce diameters across fireweed neighbourhoods (e.g., Figure 14) were similar between the control and the manual, grazing, or glyphosate brushing treatments, indicating that spruce diameter had responded little to the fireweed reductions resulting from those treatments.

Linear regressions of spruce diameter versus fireweed cover were significant ($p<0.10$) for only four of the 12 sites (Table 14). Of the significant regressions, coefficients of determination were low (adjusted r^2 0.05–0.20) and the slopes were negative but shallow (β_1 -0.006 to -0.018). These results reflect the wide variability in spruce diameter across the broad range in localized fireweed covers (0–100%) that occurred in all plantations. In contrast, linear regressions between spruce diameter and CRH were significant ($p<0.10$) for eight of the 12 sites, and their coefficients of determination moderately high compared to other sites (adjusted r^2 0.09–0.37). Fitting a negative exponential function to the diameter-CRH relationship did not improve the adjusted r^2 values. The low adjusted r^2 values and shallow, negative slopes of the diameter-cover relationships suggest that competition, as measured by fireweed cover, was of low importance and intensity to the plantations as a whole. However, the improvement in the regressions where CRH was used as an index of fireweed competition may reflect the importance of fireweed height in resource competition processes.

Lodgepole pine in the ICH zone

We have 5-year results demonstrating the effects of manual brushing on the *Fireweed* Complex and lodgepole pine in the ICH zone (Figure 15). Third-year measurements were not carried out on one of the three sites due to funding shortages that year. Instead, measurements took place in year 4, and those data have been included with fifth-year data from the two other sites (n = 3).

Description of the study sites and treatments

Three sites in the Kamloops Forest Region are being studied. The Eagle Bay site is 30 km north of Salmon Arm, in the Salmon Arm Forest District, and the Birk Creek site is 25 km southeast of Barriere, in the Kamloops Forest District. Both are in the Thompson Moist Warm ICH variant (ICHmw3). The Trophy Mountain site is in the Northern Monashee Wet Cold ESSF variant (ESSFwc2), but its vegetation characteristics make it more suitable for analysis with ICH sites than other ESSF sites. It is 20 km northeast of Clearwater, in the Clearwater Forest District.

The three sites range in elevation from 800 to 1500 m and have either northerly or easterly aspects, with slopes of 0, 45, and 60% (Table 15). Slope positions are variable (upper slope, crest, level). Soils are either Brunisolic or Podzolic and loamy in texture (silt clay loam to sandy loam). All three sites have submesic moisture regimes.

Two of the three sites were burned by wildfires prior to clearcutting and one was broadcast burned, but other than that the histories were variable. One had been logged 11 years prior to PROBE initiation and planted three times. On the other

TABLE 14 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Engelmann spruce stem diameter from the competition indices, fireweed cover and CRH, in the Fireweed Complex in the ESSF zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from fireweed cover[a]	Adjusted r^2 for linear regression predicting diameter from fireweed cover	p-value for linear regression predicting diameter from fireweed cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
11	72	5	30	$y = 2.822 - 0.011\,x$	0.05	0.03	23	$y = 2.808 - 0.007\,x$	0.09	0.01		
13	37	0	10	$y = 0.684 + 0.004\,x$	0.03	0.14	36	$y = 0.763 - 0.001\,x$	0.00	0.69		
37	60	0	60	$y = 1.308 - 0.003\,x$	0.03	0.12	100	$y = 1.438 - 0.001\,x$	0.37	0.00		
47	67	2	5	$y = 1.397 - 0.006\,x$	0.20	0.00	8	$y = 1.393 - 0.003\,x$	0.29	0.00		
48	32	0	60	$y = 0.573 + 0.001\,x$	0.00	0.49	100	$y = 0.613 - 0.000\,x$	0.00	0.44		
70	72	0	25	$y = 0.427 + 0.000\,x$	0.00	0.70	100	$y = 0.428 - 0.000\,x$	0.00	0.37		
73	71	5	70	$y = 1.952 - 0.000\,x$	0.00	0.93	76	$y = 2.523 - 0.006\,x$	0.26	0.00		
107	66	3	30	$y = 2.921 - 0.018\,x$	0.13	0.00	34	$y = 2.988 - 0.019\,x$	0.36	0.00		
108	68	2	35	$y = 1.400 - 0.007\,x$	0.02	0.13	24	$y = 1.552 - 0.009\,x$	0.31	0.00		
109	24	1	20	$y = 1.657 + 0.004\,x$	0.00	0.80	15	$y = 2.010 - 0.013\,x$	0.03	0.20		
122	63	3	50	$y = 2.373 - 0.008\,x$	0.13	0.00	38	$y = 2.438 - 0.006\,x$	0.34	0.00	$y = 2.481\,e^{(-0.003 * x)}$	0.35
124	66	2	40	$y = 2.264 + 0.002\,x$	0.00	0.75	31	$y = 2.544 - 0.007\,x$	0.04	0.08		
mean (s.e.)			36 (6)				49 (10)					

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[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is fireweed cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (fireweed cover * fireweed modal height)/spruce total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

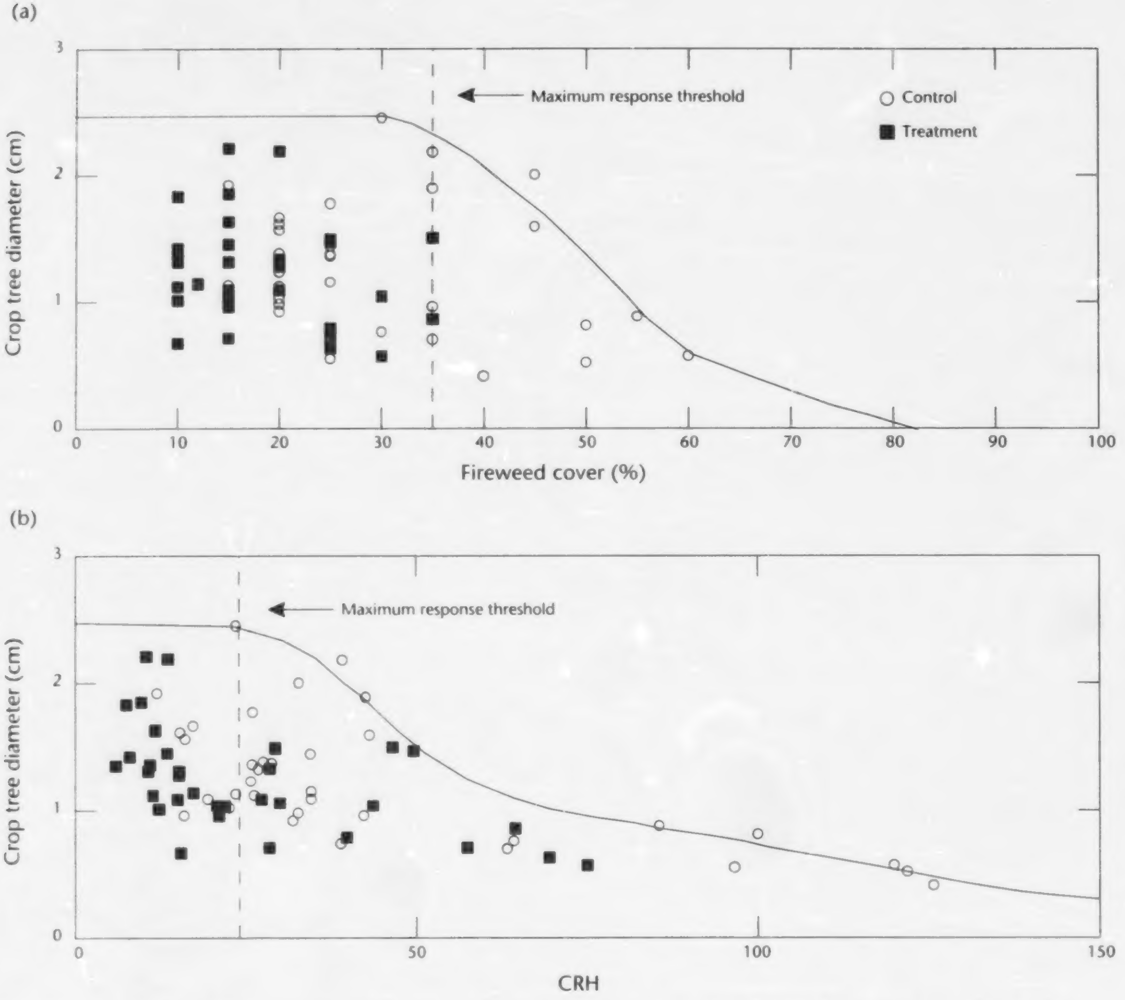


FIGURE 14 *Relationship between stem diameter of Engelmann spruce growing amongst the ESSF* Fireweed *Complex and (a) fireweed cover or (b) CRH, where CRH = (fireweed cover * fireweed modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 108 (n = 68). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover and CRH values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

two sites, only 2–3 years had passed since logging or site preparation disturbance. Seedling age was similar, however, since all three sites had been planted or re-planted with lodgepole pine within 3 years of PROBE initiation.

Prior to manual brushing, pine seedlings had mean heights of 25, 28, and 57 cm on the three sites, and were between 19 and 86% as tall as surrounding vegetation. Total conifer stocking ranged from 1714 to 1956 stems/ha, of which 1061–1200 stems/ha were well-spaced. Fireweed dominated the vegetation at all three locations, although its abundance was variable. It was most abundant on the Eagle Bay site (82% cover; 131 cm tall), and least abundant at the Birk Creek site (9% cover; 61 cm tall). In spite of the relatively light herb cover

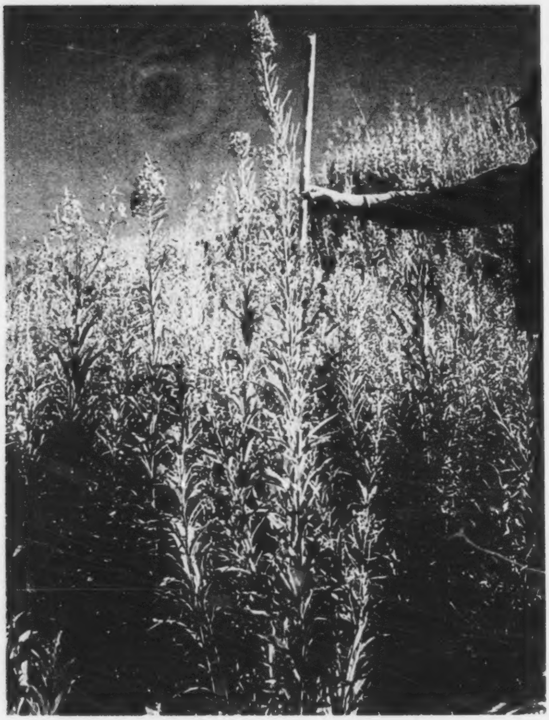


FIGURE 15 *The* Fireweed *Complex prior to manual cutting treatment at Eagle Bay (Site 50) in the ICHmw3 variant in the Salmon Arm Forest District. Photo credit: Silver Ring Forestry Ltd.*

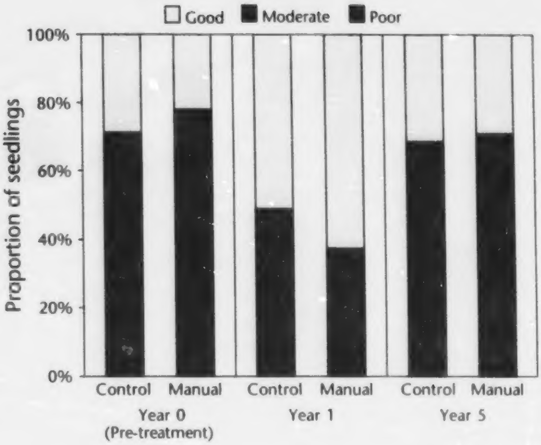


FIGURE 16 *Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 1 and 5 years after, treatment of the ICH/ESSF* Fireweed *Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

at Birk Creek, it was estimated that 25% of seedlings had been bent by snow- or vegetation-press, and would benefit from treatment. Vegetation was cut in a 1.0-m radius around target pine seedlings on two sites, and broadcast cut on a third site (Table 16). Cutting was carried out in July to release seedlings and reduce vegetation-press. A repeat treatment the following year was applied on one site because work quality had been poor in the initial treatment.

Conifer response

Survival and vigour Five years after the *Fireweed* Complex was manually cut, mean survival of 6- to 8-year-old lodgepole pine seedlings (1–3 years old at the time of treatment) was 88%, and there was no difference between the control and treatment (p = 0.33) (Table 17). Most mortality in both the control and treatment occurred at a single site (Eagle Bay), and was predominately caused by competing vegetation. Other factors responsible for minor amounts of mortality were wildlife damage, root disease, and unknown agents (<1%). Silviculture survey information collected in year 5 indicates there were an average 474 stems/ha that were free-growing, with no significant difference between the treatment and control (p = 0.28). The survey was done according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), and on some sites, it took place prior to the early assessment date.

Manual cutting resulted in a minor improvement in seedling vigour in the first year after treatment, but this disappeared by year 5 (Figure 16). Immediately prior to treatment, most seedlings were of moderate vigour and fewer than 5% were poor. Twenty-two percent of treatment seedlings and 29% of control seedlings were of good vigour before manual cutting; 1 year later the proportion had increased to 62% in the cutting treatment and 51% in the control. However, by year 5 the proportion of seedlings of good vigour had returned to about 30% in both the treatment and control, and most seedlings were again of moderate vigour.

TABLE 15 *Characteristics and history of the three replicate study sites where the ICH/ESSF* Fireweed *Complex was manually cut in lodgepole pine plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (years)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Trophy Mtn. PROBE 49 Clearwater District	ESSFwc2 04 (submesic)	1500	N 0%	Podzol/ silt clay loam	Clearcut 1981, 1985 Burned 1987 MSP 1991	9	3	0	P 1991	PSB 313B	3	57 (15)	Fireweed cover: 44 (14) Fireweed height: 78 (13)	1714	1061
Eagle Bay PROBE 50 Salmon Arm District	ICHmw3 04 (submesic)	800	N 60%	Brunisol/ silt loam	Wildfire 1991 Clearcut 1992	2	n/a	2	P 1993	PCT 313B	1	25 (5)	Fireweed cover: 82 (20) Fireweed height: 131 (46)	1845	1103
Birk Creek PROBE 65 Kamloops District	ICHmw3 05 (submesic)	1100	E 45%	Brunisol/ sandy loam	Wildfire 1964 Clearcut 1977– 1984	11	n/a	10	P 1986 P 1989 P 1994	PSB 313 PSB 415	1	28 (6)	Fireweed cover: 9 (5) Fireweed height: 61 (14) Thimbleberry cover: 10 (8) Thimbleberry ht: 41 (14)	1956	1200

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 16 *A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the ICH/ESSF* Fireweed *Complex*

Site	Initial treatment date	Treatment radius	Treatment tool	Repeat treatment
Trophy Mtn.	July 1994	Broadcast	Weed whacker	None
Eagle Bay	July 14, 1994	1.0 m	Weed whacker	None
Birk Creek	July 23, 1995	1.0 m	Weed whacker and hand-pulling	August 1996

TABLE 17 *Survival and growth responses of lodgepole pine seedlings to manual cutting in the ICH/ESSF* Fireweed *Complex*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	95	84	7.856	0.42
5 yr post-treatment	94	81	6.645	0.33
Stem diameter (cm)				
Pre-treatment	0.65	0.68	0.027	0.45
1 yr post-treatment	1.15	1.10	0.053	0.55
5-yr post-treatment	3.86	3.75	0.296	0.82
Diameter increment (cm)				
1 yr post-treatment	0.51	0.43	0.030	0.19
5 yr post-treatment	0.80	0.75	0.056	0.60
Height (cm)				
Pre-treatment	35.7	36.9	1.527	0.64
1 yr post-treatment	57.2	60.0	4.659	0.71
5 yr post-treatment	181.6	180.7	10.778	0.96
Leader length (cm)				
1 yr post-treatment	20.0	22.0	2.880	0.68
5 yr post-treatment	36.8	40.0	1.778	0.33
Height:diameter ratio				
Pre-treatment	57.9	56.7	1.375	0.60
1 yr post-treatment	51.1	56.1	0.905	0.06*
5 yr post-treatment	48.7	51.7	1.102	0.20

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\hat{y}$) was calculated as $S_{\hat{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

Growth Five years after manual cutting of the *Fireweed* Complex, there were no significant differences in pine seedling height, leader length, stem diameter, stem diameter increment, or height:diameter ratio ($p>0.10$) (Table 17, Figure 17). In year 1, height:diameter ratio was significantly lower in the manual cutting treatment (51.1) than the control (56.1), suggesting that seedlings were becoming sturdier in response to treatment ($p = 0.06$). However, by year 5, this effect had disappeared and height:diameter ratio was similar in the treatment and control (average 50.2). Pine seedlings were 5–8 years old at that time and averaged 181.2 cm tall, with 38.4-cm leaders and 3.81-cm stem diameters.

Frequency counts in lodgepole pine standardized stem diameter and height classes were reasonably normally distributed prior to brushing, and were similar in the manual cutting treatment and the control (Figures 18 and 19). The distributions changed little during the 5-year measurement period, which is consistent with ANOVA results that the cutting treatment had no effect on pine diameter or height growth.

Competitive status Manual cutting improved the competitive status of lodgepole pine seedlings for 1 year, but by year 5 seedlings in the treatment and control were outgrowing vegetation equally well (Figure 20). Prior to manual cutting, fewer than 10% of lodgepole pine seedlings were above the *Fireweed* Complex. One year later, one-third of seedlings in the manual cutting treatment were free of surrounding vegetation, compared with 8% of control seedlings. However, by year 5, 58% of treatment seedlings and 54% of control seedlings were above the canopy and almost none continued to be overtopped.

Plant community responses

Abundance Prior to manual cutting, fireweed dominated the plant community with an average cover of 45.1% (Table 18). Manual cutting had no significant effect on height or cover of fireweed after 1 or 5 years (Figure 21), nor did it affect

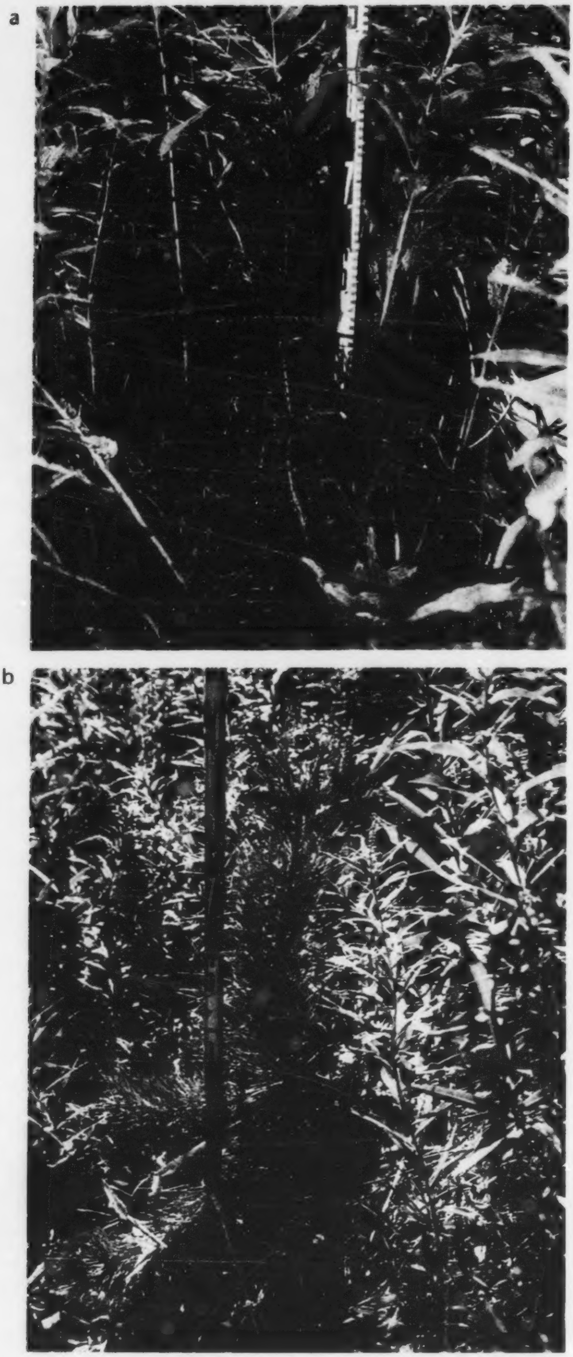


FIGURE 17 *Lodgepole pine seedlings in the (a) treatment and (b) control 5 years following manual cutting at Eagle Bay. The treatment had no effect on pine performance. Photo credit: Silver Ring Forestry Ltd.*

TABLE 18 *Cover and height of vegetation in the ICH/ESSF Fireweed Complex before and after manual cutting in lodgepole pine plantations*

	Means			
Response variable	**Manual cutting**	**Control**	**Standard error**	**p-value**
Fireweed				
Cover (%)				
Pre-treatment	43.6	46.6	0.216	0.01*
1 yr post-treatment	36.2	42.6	1.788	0.89
5 yr post-treatment	28.1	31.5	1.692	0.30
Height (cm)				
Pre-treatment	85.2	94.5	6.512	0.42
1 yr post-treatment	102.2	126.5	7.317	0.14
5 yr post-treatment	86.0	98.9	6.183	0.28
All vegetation				
Cover (%)				
Pre-treatment	72.7	78.4	3.290	0.35
1 yr post-treatment	80.6	84.9	4.105	0.53
5 yr post-treatment	84.6	86.7	3.000	0.67
Height (cm)				
Pre-treatment	79.4	89.6	6.559	0.39
1 yr post-treatment	79.4	101.6	8.751	0.21
5 yr post-treatment	85.7	87.0	11.448	0.94
Herbs				
Cover (%)				
Pre-treatment	58.5	69.4	5.940	0.32
1 yr post-treatment	62.5	74.5	7.635	0.38
5 yr post-treatment	57.9	66.3	7.034	0.49
Height (cm)				
Pre-treatment	72.7	86.0	5.116	0.21
1 yr post-treatment	70.1	90.9	8.009	0.21
5 yr post-treatment	64.2	60.7	12.364	0.86
Shrubs				
Cover (%)				
Pre-treatment	19.9	13.3	1.860	0.13
1 yr post-treatment	20.9	17.9	2.814	0.53
5 yr post-treatment	27.1	25.6	2.217	0.67
Height (cm)				
Pre-treatment	48.2	56.6	1.059	0.03*
1 yr post-treatment	54.0	53.4	7.244	0.55
5 yr post-treatment	98.4	99.0	6.681	0.96

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

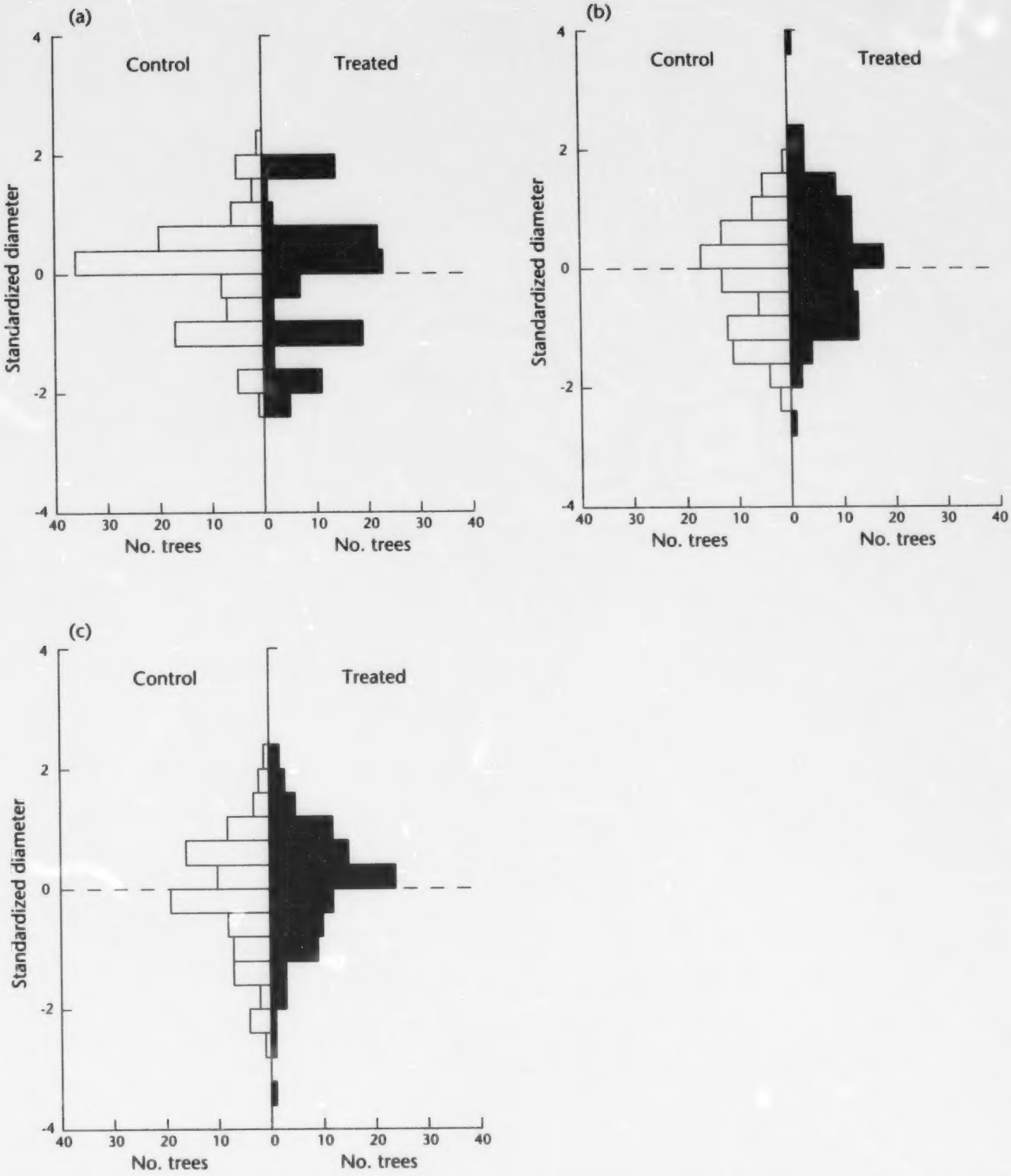


FIGURE 18 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the ESSF/ICH* Fireweed *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 5 years post-treatment.*

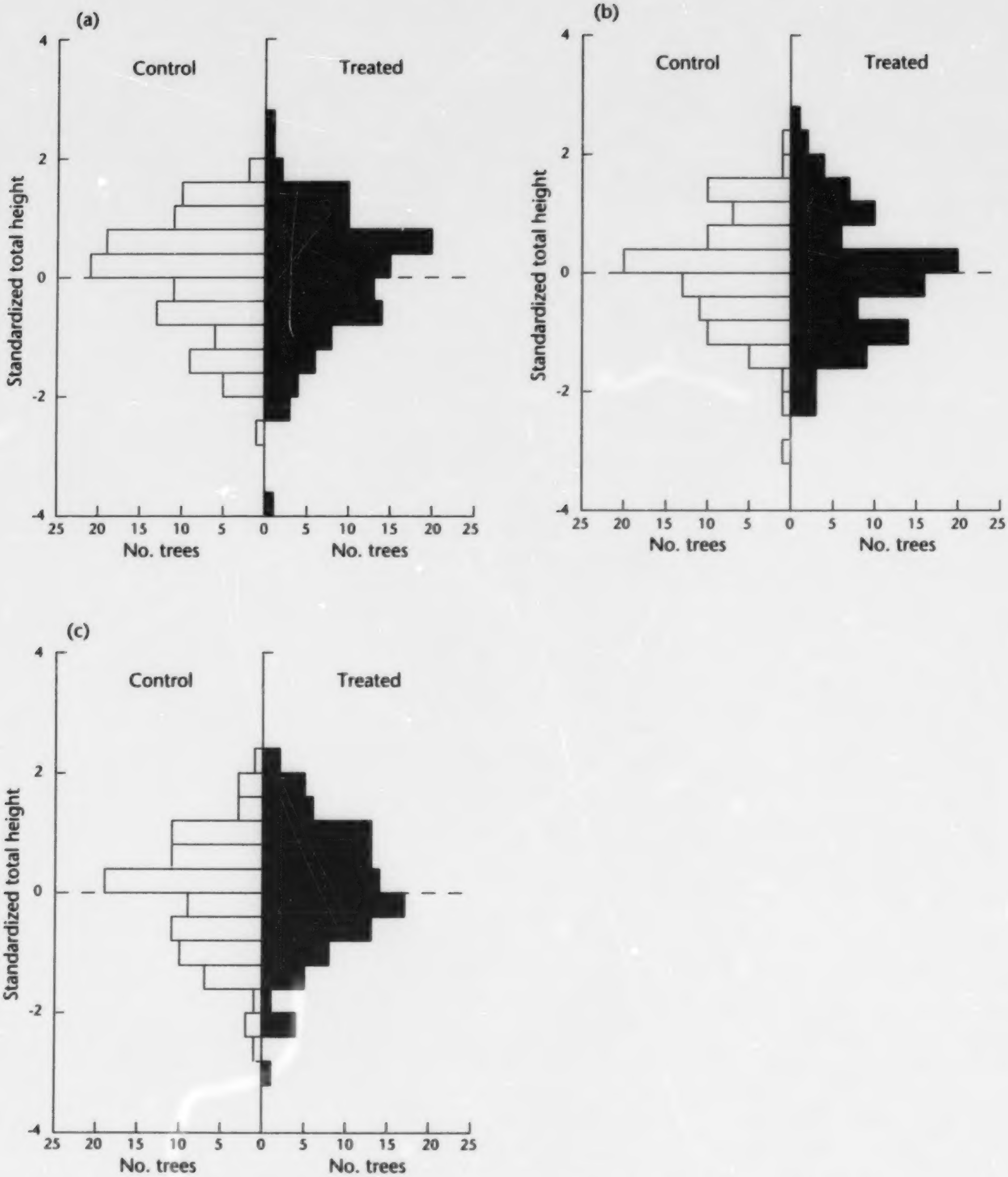


FIGURE 19 *Frequency of control and treated trees in standardized total height classes ($\mu = 0$; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the ESSF/ICH* Fireweed Complex *before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 5 years post-treatment.*

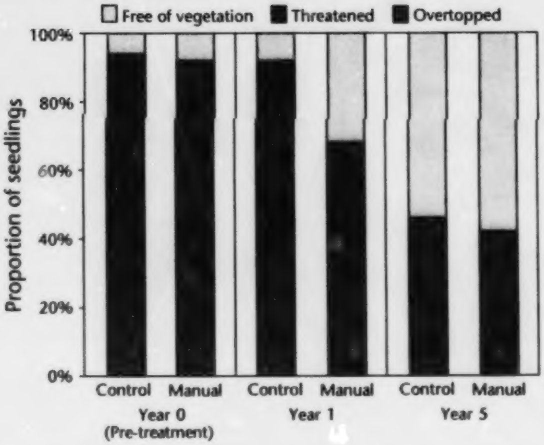


FIGURE 20 *Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 1 and 5 years after, treatment of the ICH/ESSF* Fireweed *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

FIGURE 21 *The* Fireweed *Complex 1 year following manual cutting at Eagle Bay. Vegetation was cut in a 1.0-m radius around seedlings, and had recovered to control levels within 1 year of treatment. Photo credit: Silver Ring Forestry Ltd.*

height or cover of all vegetation, the herb layer, or the shrub layer (p>0.10). One year after manual cutting, fireweed averaged 39.4% cover and was 114.4 cm tall. Mean overall vegetation cover and height were 82.8% and 90.5 cm, respectively. Vegetation abundance was essentially the same in year 5.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the *Fireweed* Complex had no effect on either species richness or species diversity (p>0.10) (Table 19). Average species richness increased between the pre-treatment (24 species) and first-year (32 species) assessments, but this is likely due to differences in the assessment date. Pre-treatment assessments for manually brushed *Fireweed* Complex sites are often carried out early in the season to accommodate brushing schedules, whereas subsequent assessments are carried out when vegetation is at its peak. By year 5, richness in the control had increased further in comparison to the treatment, but because of variability between sites the difference remained statistically insignificant (average 34 species, p>0.10). There were no significant differences in richness or diversity of structural vegetation groups between the treatment and control (p>0.10) (Table 20).

TABLE 19 *Richness and diversity of vascular plant species in the ICH/ESSF* Fireweed *Complex before and after manual cutting in lodgepole pine plantations*

	Means			
Response variable	**Manual cutting**	**Control**	**Standard error**	**p-value**
Richness				
Pre-treatment	24.33	23.67	0.471	0.42
1 yr post-treatment	31.00	33.00	1.080	0.32
5 yr post-treatment	31.00	37.00	2.121	0.30
Shannon-Weaver Diversity Index				
Pre-treatment	1.67	1.85	0.111	0.38
1 yr post-treatment	1.84	1.90	0.041	0.44
5 yr post-treatment	2.08	2.05	0.013	0.32
Simpson's Diversity Index				
Pre-treatment	0.64	0.69	0.041	0.48
1 yr post-treatment	0.69	0.70	0.003	0.34
5 yr post-treatment	0.75	0.74	0.004	0.52

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 20 *Richness and diversity of structural vegetation groups in the ICH/ESSF* Fireweed *Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means Manual cutting	 Control	Standard error	p-value
Richness				
Pre-treatment	6.67	6.00	0.236	0.18
1 yr post-treatment	6.67	6.67	0.000	1.00
5 yr post-treatment	7.00	7.00	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.02	1.03	0.094	0.94
1 yr post-treatment	1.10	1.03	0.023	0.16
5 yr post-treatment	1.23	1.17	0.100	0.74
Simpson's Diversity Index				
Pre-treatment	0.51	0.51	0.055	0.97
1 yr post-treatment	0.56	0.51	0.013	0.13
5 yr post-treatment	0.59	0.57	0.039	0.75

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

Manual treatments had very little effect on the abundance of individual shrub and herb species associated with the *Fireweed* Complex on the three sites in this treatment cell. Willow increased in the treated plots relative to the control on two of three sites, but otherwise there were no trends for individual species that could be followed across multiple sites (Table 21). Cover estimates for individual species tended to be higher in the first year than the pre-treatment assessment, but the frequency of increases was similar in the treatment and the control, suggesting that differences were related to either the timing of assessment or to assessor subjectivity. Berry-producing shrubs such as black huckleberry, thimbleberry, and red raspberry were present in varying amounts on these sites, but manual cutting did not affect their abundance.

Competition thresholds

This section summarizes thresholds for ICH/ESSF pine plantations where fireweed was brushed using either manual or glyphosate methods (n = 5). The fireweed cover and CRH thresholds for lodgepole pine diameter growth in the ICH/ESSF zones were 40 and 49%, respectively, where CRH = (fireweed cover * fireweed modal height)/pine height (e.g., Figure 22).

TABLE 21 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH/ESSF* Fireweed *Complex in lodgepole pine plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves			*Populus tremuloides* (< 2m)
Tall shrubs	*Salix* spp.		
Low shrubs			*Pachistima myrsinites* *Ribes lacustre* *Rubus idaeus* *Rubus parviflorus* *Sambucus racemosa* *Vaccinium membranaceum*
Herbs			*Anaphalis margaritacea* *Cirsium vulgare* *Clintonia uniflora* *Cornus canadensis* *Epilobium angustifolium* Grass spp. *Hieracium albiflorum* *Smilacina racemosa* *Taraxacum officinale*

The thresholds varied widely among sites, which may be related to the range in stand ages (0–5 years) (Table 22). The thresholds for fireweed cover and, to a lesser extent CRH, were generally vague (e.g., Figure 22).

A small proportion of trees (16–26%) were growing in fireweed neighbourhoods above the thresholds, and may therefore benefit from further selective brushing. Most trees above the thresholds were control trees (82–85%), whereas over half below the thresholds were treated trees (57–58%). Most treated trees (89–95%) fell below the

TABLE 22 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting lodgepole pine stem diameter from the competition indices, fireweed cover and CRH, in the Fireweed Complex in the ICH/ESSF zones*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from fireweed cover[a]	Adjusted r^2 for linear regression predicting diameter from fireweed cover[a]	p-value for linear regression predicting diameter from fireweed cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[c]
11	72	5	20	-	-	-	43	-	-	-
35	71	3	20	$y = 3.776 - 0.012x$	0.03	0.09	30	$y = 3.931 - 0.036x$	0.18	0.00
49	72	3	55	$y = 3.16 - 0.016x$	0.05	0.03	34	$y = 3.945 - 0.019x$	0.02	0.10
50	49	1	85	$y = 1.985 - 0.006x$	0.02	0.17	112	$y = 1.972 - 0.003x$	0.27	0.00
65	72	0	20	$y = 1.014 - 0.014x$	0.13	0.00	24	$y = 0.993 - 0.005x$	0.26	0.00
mean (s.e.)			40 (13)				49 (17)			

[a] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is fireweed cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (fireweed cover * fireweed modal height)/pine total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

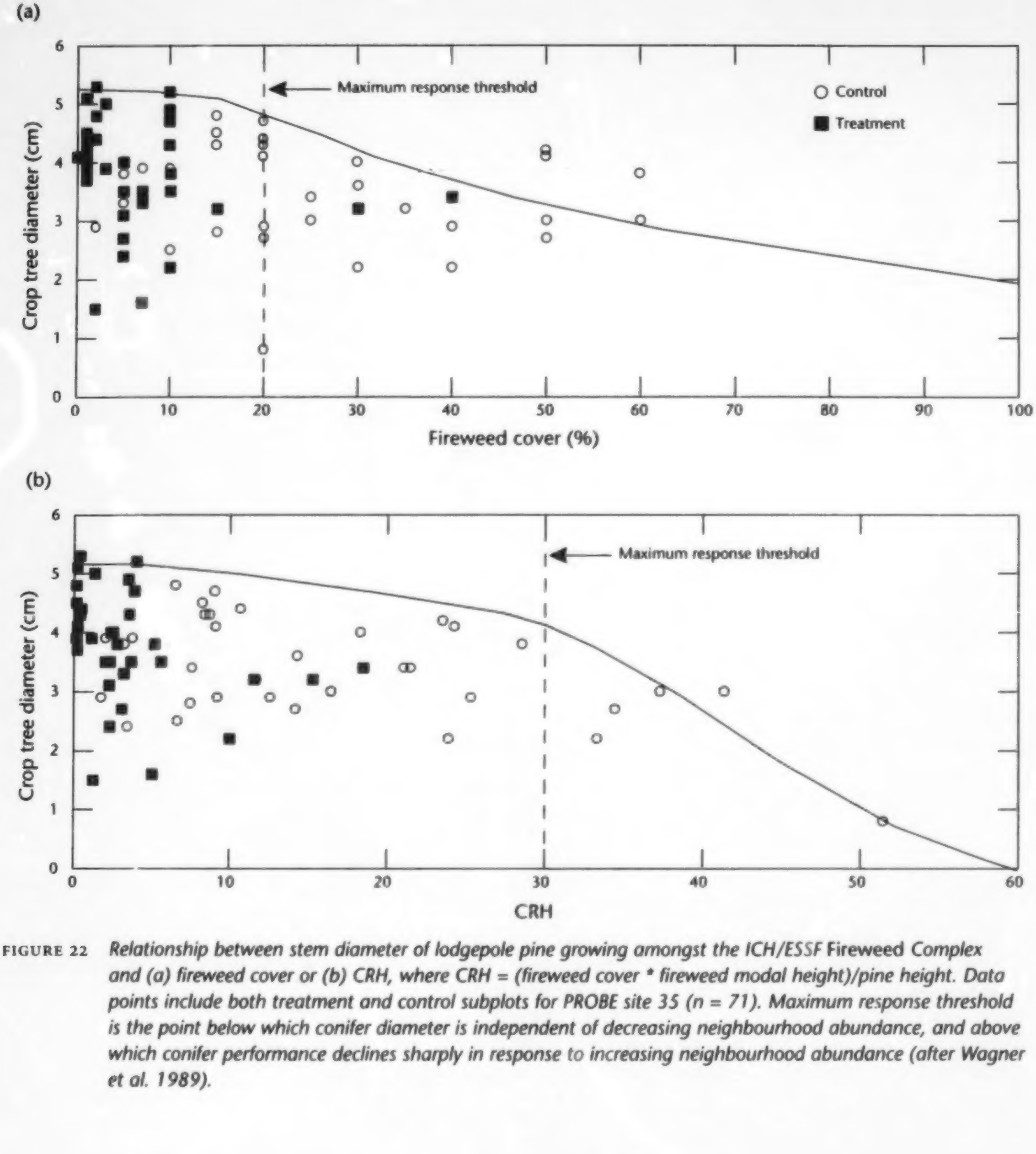


FIGURE 22 *Relationship between stem diameter of lodgepole pine growing amongst the ICH/ESSF Fireweed Complex and (a) fireweed cover or (b) CRH, where CRH = (fireweed cover * fireweed modal height)/pine height. Data points include both treatment and control subplots for PROBE site 35 (n = 71). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

thresholds, indicating that brushing successfully reduced fireweed abundance below the competition thresholds, at least temporarily. However, only 5% of treated trees that occurred below the fireweed thresholds achieved ≥80% of the maximum diameter measured on the site. In addition, both the means ($p>0.10$) (Table 17) and the distributions of pine diameters across fireweed neighbourhoods (e.g., Figure 22) were similar between the control and manual treatment, suggesting that pine diameter had not responded to the short-term fireweed reductions. On the glyphosate-treated sites, however, 10% of the largest-diameter trees were treated trees that fell below the competition thresholds

(Figure 23). This result suggests that glyphosate treatments have the potential to improve lodgepole pine growth in the *Fireweed* Complex.

Linear regressions were significant ($p<0.10$) for three sites where fireweed cover was used as the competition index, and four sites where CRH was used (Table 22). Of the significant regressions, coefficients of determination were very low (adjusted r^2 0.03–0.13 for cover regressions, 0.18–0.27 for CRH regressions) and the slopes were negative but shallow (β_1 -0.006 to -0.016 for cover regressions, -0.003 to -0.036 for CRH regressions). These results suggest that there were weak relationships between pine diameter and our two measures of fireweed competition. The low adjusted r^2 values and shallow, negative slopes of the regressions suggest that fireweed competition was of low importance and intensity to these plantations as a whole.

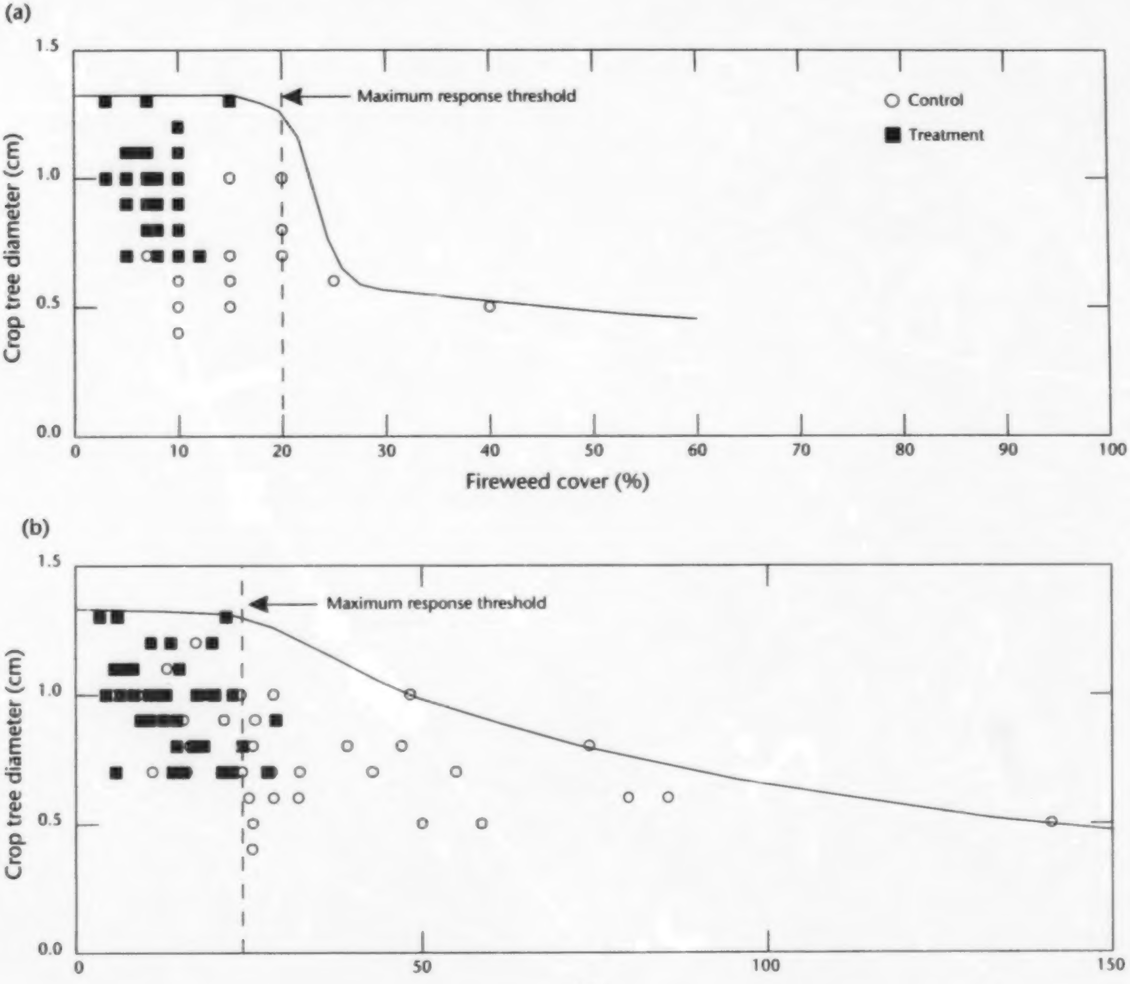


FIGURE 23 *Relationship between stem diameter of lodgepole pine growing amongst the ICH/ESSF* Fireweed Complex *and (a) fireweed cover or (b) CRH, where CRH = (fireweed cover * fireweed modal height)/pine height. Data points include both treatment and control subplots for PROBE site 65 (n = 72). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

Ground Foliar Glyphosate Application

This section describes fifth-year responses of Engelmann spruce seedlings and vegetation to broadcast ground foliar glyphosate applications in the ESSF *Fireweed* Complex (n = 3) (Figure 24). Spruce seedlings were 2–4 years old at the time of treatment.

Engelmann spruce in the ESSF zone

Description of the study sites and treatments

Three study sites are being measured for this treatment cell. Two of the sites are in the Vernon District of the Kamloops Forest Region; the Chase Creek site is 25 km northeast of Falkland in the Thompson Dry Cold ESSF variant (ESSFdc2) and the Torrent Creek site is 42 km northeast of Lumby in the Northern Monashee Wet Cold ESSF variant (ESSFwc2). The Bush River site is 120 km northwest of Golden, in the Golden District of the Nelson Forest Region. Although it was in the Golden Moist Warm ICH variant (ICHmw1), it is more similar to the ESSF sites than other ICH sites.

Physiographic features, site histories, and conifer and vegetation characteristics for each site are summarized in Table 23. The three sites are located between 1100 and 1600 m elevation, on shallow slopes (10–25%). Aspect was variable (northwest, north, east), and so was slope position (mid, upper-mid, toe). All three sites were mesic, and had Brunisolic soils of silt-loam texture.

FIGURE 24 *The* Fireweed *Complex prior to glyphosate treatment at Bush River (Site 122) in the ICHmw1 variant in the Golden Forest District. Photo credit: JMJ Holdings Inc.*

History of the three sites was variable. They were all clearcut 11–13 years prior to the initiation of PROBE, and two were mechanically prepared prior to planting. The delay between harvesting or site preparation and planting ranged from 2 to 8 years. When PROBE was initiated, spruce seedlings were 1, 2, and 5 years old on the three sites, and ranged in height from 29 to 52 cm. Total conifer stocking on the three sites ranged from 1283 to 3569 stems/ha, of which 897–1190 stems/ha were well spaced. Seedlings in the 5-year-old plantation were almost as tall as fireweed, while those in the two younger plantations were only about one-third as tall. Fireweed had mean pre-treatment cover values of 25–77% and was between 72 and 138 cm tall on the three sites. It was the dominant species at all locations, although Sitka valerian cover was extensive at Torrent Creek.

Glyphosate was applied to the *Fireweed* Complex in mid-August at rates of 1.4–2.1 kg ai/ha, using either backpack sprayers or aerial spray (Table 24). It was sprayed around individual seedlings at one site, and broadcast sprayed at the other two.

Conifer response

Survival and vigour Five years after glyphosate application, survival of the 6- to 10-year-old Engelmann spruce seedlings (1–5 years old at the time of treatment) averaged 91%, and there was no difference between the treatment and control (p = 0.34) (Table 25). Competing vegetation was responsible for approximately three-quarters of the mortality in the control and half the mortality in the treatment. The remainder of seedling mortality was caused by unidentified agents. Silviculture survey information collected in year five indicates there were 784 and 332 free-growing stems/ha in the treatment and control, respectively (p = 0.07). The surveys were conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), and on some sites, they took place before the early assessment date.

Seedling vigour declined during the 5-year monitoring period, but to a greater extent in the control than the treatment (Figure 25). Prior to glyphosate application, 50% of the 1- to 5-year-old seedlings were of good vigour, 45% were of moderate vigour, and 5% were of poor vigour. One year later, the proportion of seedlings of good vigour had decreased to about 30% in both the control and treatment, while the proportion of poor seedlings had increased to 13% in the treatment and 22% in the control. By year 5, 35% of treated seedlings

TABLE 23 *Characteristics and history of the three replicate study sites where the ESSF/ICH Fireweed Complex was treated with foliar glyphosate spray in Engelmann spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (years)	Origin[b]	Stock	Age[c] (years)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Chase Creek PROBE 11 Vernon District	ESSFdc2 01 (mesic)	1400	NW 25%	Brunisol/ silt loam	Clearcut 1978	13	n/a	8	P 1986	2+0 BR	5	52 (14)	Fireweed cover: 25 (24) Fireweed height: 72 (13)	3569	1190
Torrent Creek PROBE 47 Vernon District	ESSFwc2 01 (mesic)	1600	N 10%	Brunisol/ silt loam	Clearcut 1983 Pile and burn 1991	11	3	3	P 1986	PSB 415 2+0	2	29 (6)	Fireweed cover: 58 (20) Fireweed height: 105 (19) Valerian cover: 33 (15) Valerian height: 80 (21)	1892	1148
Bush River PROBE 122 Golden District	ICHmw1 01 (mesic)	1100	E 18%	Brunisol/ silt loam	Clearcut 1981/82 Windrow 1984 Chemical 1991	12	2	2	P 1985 P 1988 P 1992	PSB 415B PSB 312A	1	40 (6)	Fireweed cover: 77 (12) Fireweed height: 138 (15)	1283	897

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting

[b] Origin: P = planted; N = natural regeneration

[c] Age refers to the number of years since planting

[d] Values are means and one standard deviation (in parentheses)

TABLE 24 *A description of foliar glyphosate treatments applied to the three replicate study sites to release Engelmann spruce seedlings growing in the ESSF/ICH* Fireweed *Complex*

Site	Initial treatment date	Application method	Application tools	Application rate (kg ai/ha)	Weather at treatment	Precipitation after treatment
Chase Creek	August 15–18, 1993	Spot ground foliar spray	Backpack sprayer	1.4	Unknown	None
Torrent Creek	August 23, 1994	Broadcast ground foliar spray	Backpack sprayer	1.78	Overcast 74–100% RH	None
Bush River	August 22–23, 1994	Broadcast aerial spray	n/a	2.1	9.5–13°C 80–86% RH No wind	August 23 5.8 mm August 24–30 2.3 mm

were of good vigour compared to 20% of control seedlings. Most of the remainder were of moderate vigour, although there continued to be a greater proportion of poor seedlings in the control than the treatment (17 versus 7%).

Growth Five years after glyphosate treatment, there were no significant differences in Engelmann spruce height (average 105.5 cm), leader length (average 17.2 cm), stem diameter (average 2.43 cm), or diameter increment (average 0.44 cm) between

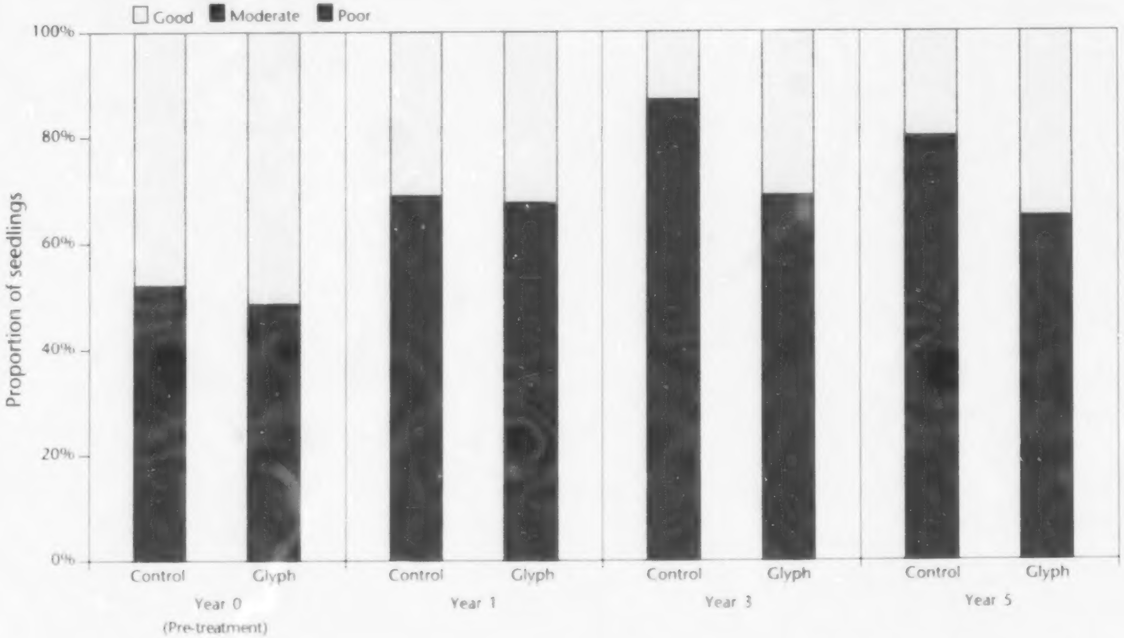


FIGURE 25 *Comparison of Engelmann spruce vigour between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH* Fireweed *Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

TABLE 25 *Survival and growth responses of Engelmann spruce seedlings to foliar glyphosate spray in the ESSF/ICH Fireweed Complex*

Response variable	Means		Standard error	p-value
	Glyphosate	Control		
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	98	97	0.653	0.42
3 yr post-treatment	95	92	3.642	0.55
5 yr post-treatment	94	88	3.645	0.34
Stem diameter (cm)				
Pre-treatment	0.80	0.74	0.025	0.25
1 yr post-treatment	0.95	0.88	0.018	0.11
3 yr post-treatment	1.75	1.43	0.077	0.09*
5 yr post-treatment	2.80	2.06	0.189	0.11
Diameter increment (cm)				
1 yr post-treatment	0.27	0.20	0.030	0.23
3 yr post-treatment	0.41	0.28	0.048	0.20
5 yr post-treatment	0.53	0.34	0.061	0.15
Height (cm)				
Pre-treatment	40.9	40.1	0.693	0.46
1 yr post-treatment	48.0	48.2	1.015	0.87
3 yr post-treatment	73.7	69.1	3.385	0.44
5 yr post-treatment	116.0	95.0	8.258	0.22
Leader length (cm)				
Pre-treatment	4.3	4.5	0.151	0.38
1 yr post-treatment	7.7	8.3	0.297	0.31
3 yr post-treatment	15.9	10.4	2.744	0.29
5 yr post-treatment	20.7	13.7	1.913	0.12
Height:diameter ratio				
Pre-treatment	51.4	53.4	1.231	0.36
1 yr post-treatment	52.2	57.1	0.552	0.02*
3 yr post-treatment	42.1	48.3	0.465	0.01*
5 yr post-treatment	41.9	46.9	0.865	0.05*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

the control and treatment (p>0.10) (Table 25). Height:diameter ratio was lower in the treatment than control in year 1 (52.2 versus 57.1, p = 0.02), year 3 (42.1 versus 48.3, p = 0.01), and year 5 (41.9 versus 46.9, p = 0.05). Engelmann spruce stem diameter was larger in the glyphosate treatment than in the control in year 3 (1.75 versus 1.43 cm, p = 0.09) (Figure 26), but the difference was no longer significant in year 5.

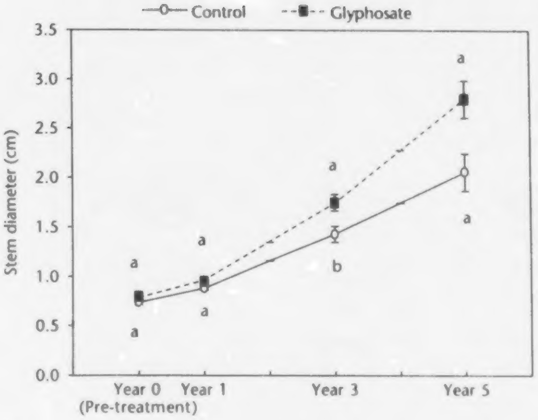


FIGURE 26 *Comparison of Engelmann spruce stem diameter between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH Fireweed Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (α = 0.10).*

The standardized distributions of spruce diameter were more or less normal in both the treatment and control prior to treatment. During the 5-year measurement period, control seedlings tended to shift into smaller-diameter classes, whereas treated seedlings tended to shift into larger classes (Figure 27). This suggests that the glyphosate treatment improved growing conditions for some spruce, relative to those in the control, but the continued presence of numerous treated trees in the -1 to -2 diameter classes indicates that the response to glyphosate was not universal. The diameter distributions suggest that the response to treatment became more pronounced between years 3 and 5, which differs from ANOVA results, in which differences in stem diameter between the treatment and control were significant in year 3, but not year 5. The frequency of spruce in smaller height classes also increased in the control during the 5-year measurement period, while some treated spruce shifted into taller classes (Figure 28). According to ANOVA, there were no differences in spruce height by year 5, but it is possible that the trend

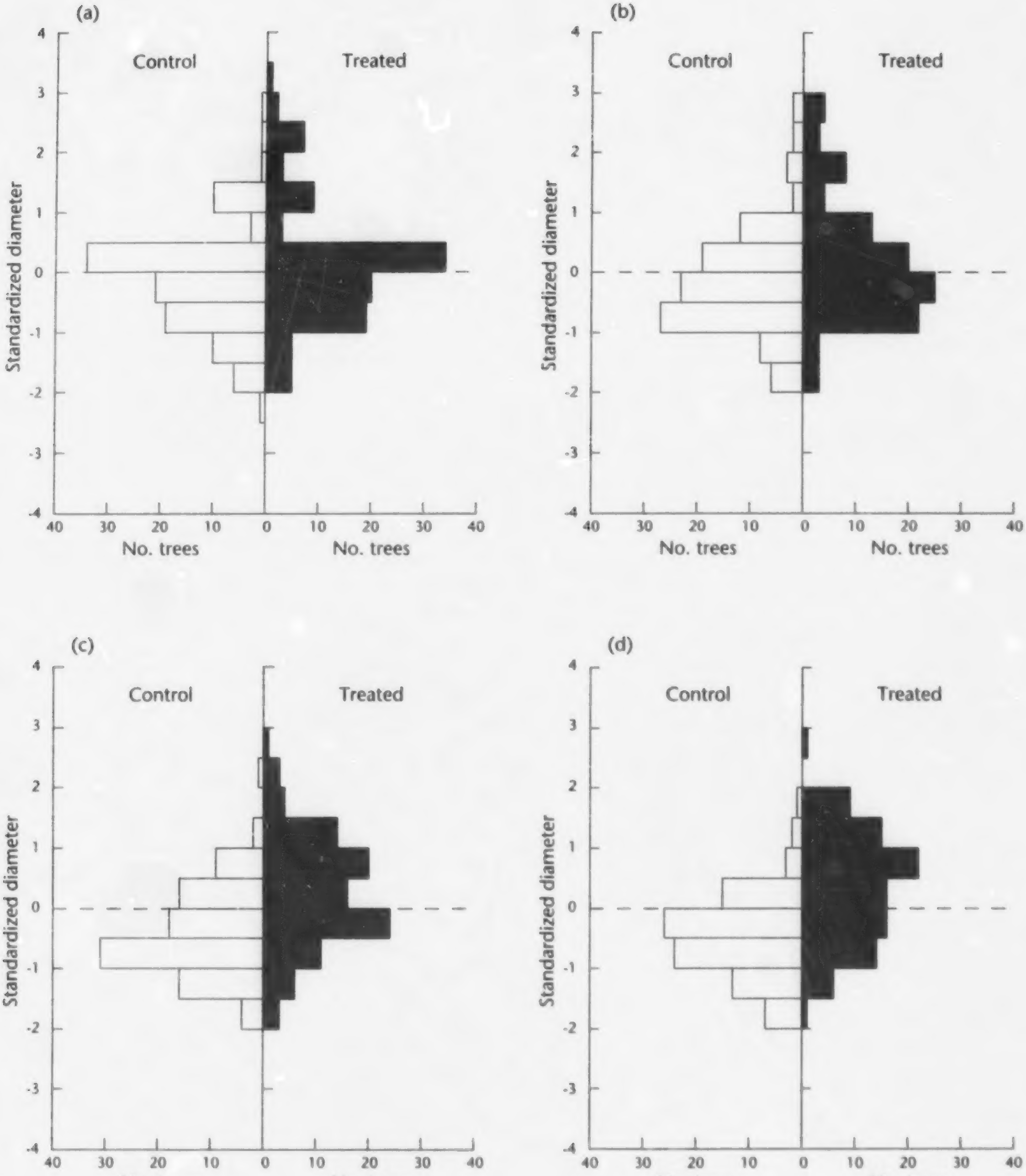


FIGURE 27 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Engelmann spruce in the ESSF/ICH* Fireweed Complex *before and after glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

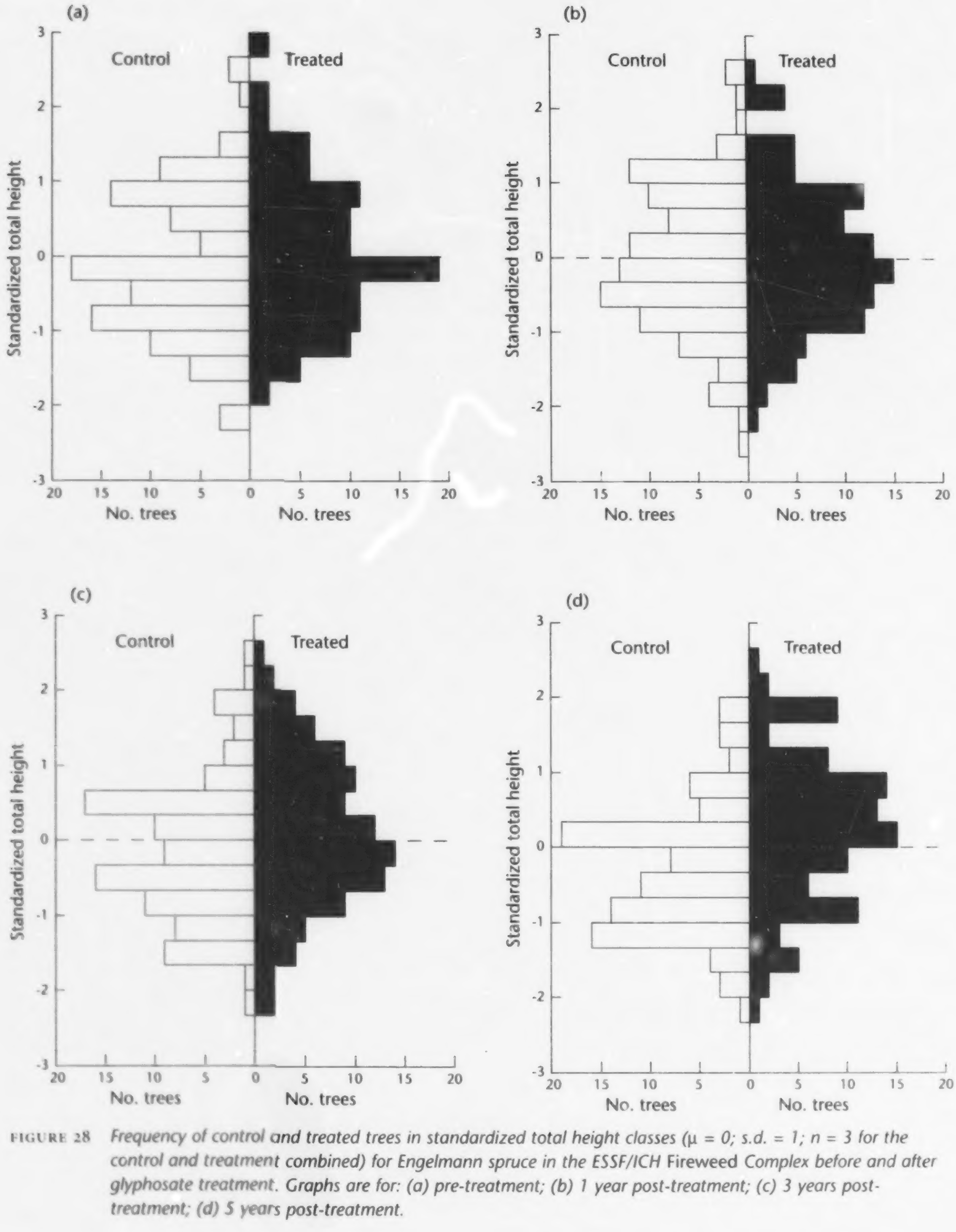


FIGURE 28 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Engelmann spruce in the ESSF/ICH* Fireweed *Complex before and after glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

illustrated by the distributions may eventually become statistically significant.

Competitive status Brushing with glyphosate improved the competitive status of Engelmann spruce seedlings in year 1 and the effect lasted through year 5 (Figure 29). Prior to treatment, approximately two-thirds of seedlings were overtopped by vegetation in both the control and glyphosate treatment. One year after glyphosate application, 22% of seedlings were overtopped in treated plots compared to 58% in the control; after 5 years, 32% of treated seedlings were overtopped compared with 71% of control seedlings. At the start of the trial, approximately one-third (29%) of seedlings were above surrounding vegetation. Five years later, 47% of treated seedlings were free of vegetation, compared to 13% of control seedlings.

Plant community response

Abundance Glyphosate reduced cover and height of fireweed for at least 5 years (Table 26, Figure 30). Prior to treatment, fireweed cover and height averaged 53.1% and 104.5 cm, respectively. One year later, fireweed cover was reduced to 11.3% in the treatment compared to 54.0% in the control (p = 0.01) (Figure 31), and fireweed height was reduced to 41.3 cm in the treatment compared to 106.9 cm in the control (p = 0.03) (Figure 32). Fireweed recovered slowly, and, by year 5, differences in cover (15.3% in the glyphosate treatment versus 45.5% in the control, p = 0.07) and height (99.5 cm in the glyphosate treatment versus 114.8 cm in the control, p = 0.05) continued to be significant.

Glyphosate also reduced abundance of the herb layer, in comparison to the control, for 1 year. In the first post-treatment assessment, herb height was reduced by approximately two-thirds (p = 0.02) and herb cover by about one-quarter (p = 0.05); however, by year 3 both height and cover had completely recovered. Overall vegetation height and cover were similarly reduced for 1 year (p<0.10), but while height recovered to control levels by year 3, differences in cover continued to be marginally significant in year 5 (p = 0.09). Glyphosate also affected abundance of the shrub layer, but

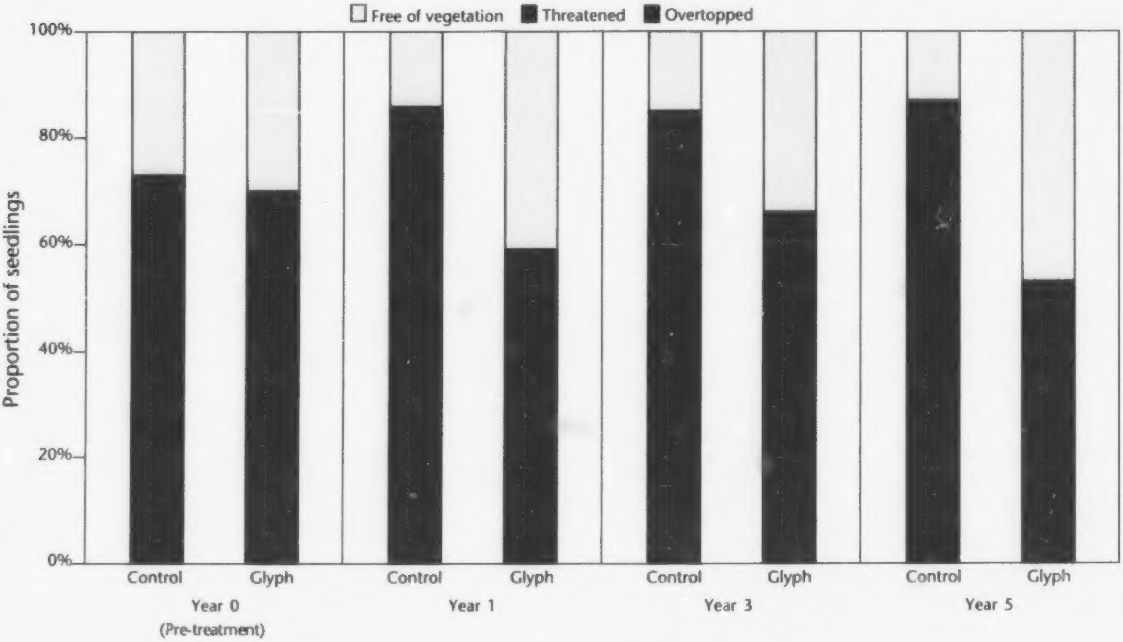


FIGURE 29 *Comparison of Engelmann spruce competitive status between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH Fireweed Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

TABLE 26 *Cover and height of vegetation in the ESSF/ICH Fireweed Complex before and after glyphosate treatment in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Glyphosate	Control		
Fireweed				
Cover (%)				
Pre-treatment	47.5	58.6	11.145	0.55
1 yr post-treatment	11.3	54.0	2.512	0.01*
3 yr post-treatment	17.4	57.6	0.384	0.00*
5 yr post-treatment	15.3	45.5	5.808	0.07*
Height (cm)				
Pre-treatment	85.5	123.5	18.581	0.29
1 yr post-treatment	41.3	106.9	8.076	0.03*
3 yr post-treatment	103.3	125.7	3.902	0.06*
5 yr post-treatment	99.5	114.8	2.396	0.05*
All vegetation				
Cover (%)				
Pre-treatment	76.6	87.4	7.688	0.42
1 yr post-treatment	61.2	85.3	3.565	0.04*
3 yr post-treatment	80.8	87.7	2.290	0.17
5 yr post-treatment	82.0	89.1	1.665	0.09*
Height (cm)				
Pre-treatment	72.9	102.7	17.260	0.35
1 yr post-treatment	37.9	104.0	4.069	0.01*
3 yr post-treatment	81.9	126.7	13.429	0.14
5 yr post-treatment	80.5	115.7	10.012	0.13
Herbs				
Cover (%)				
Pre-treatment	72.0	80.9	7.453	0.49
1 yr post-treatment	58.6	79.7	3.609	0.05*
3 yr post-treatment	74.6	80.2	4.014	0.43
5 yr post-treatment	72.8	72.3	3.445	0.93
Height (cm)				
Pre-treatment	70.5	104.9	18.157	0.31
1 yr post-treatment	35.2	103.3	6.115	0.02*
3 yr post-treatment	80.5	125.8	13.822	0.15
5 yr post-treatment	76.1	113.2	12.177	0.16
Shrubs				
Cover (%)				
Pre-treatment	9.2	16.6	2.715	0.19
1 yr post-treatment	3.7	18.3	3.736	0.11
3 yr post-treatment	13.9	24.8	7.053	0.39
5 yr post-treatment	19.5	40.1	2.948	0.04*
Height (cm)				
Pre-treatment	58.1	70.9	5.348	0.23
1 yr post-treatment	50.7	73.0	3.180	0.04*
3 yr post-treatment	58.5	86.6	4.624	0.05*
5 yr post-treatment	65.7	101.5	8.237	0.09*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

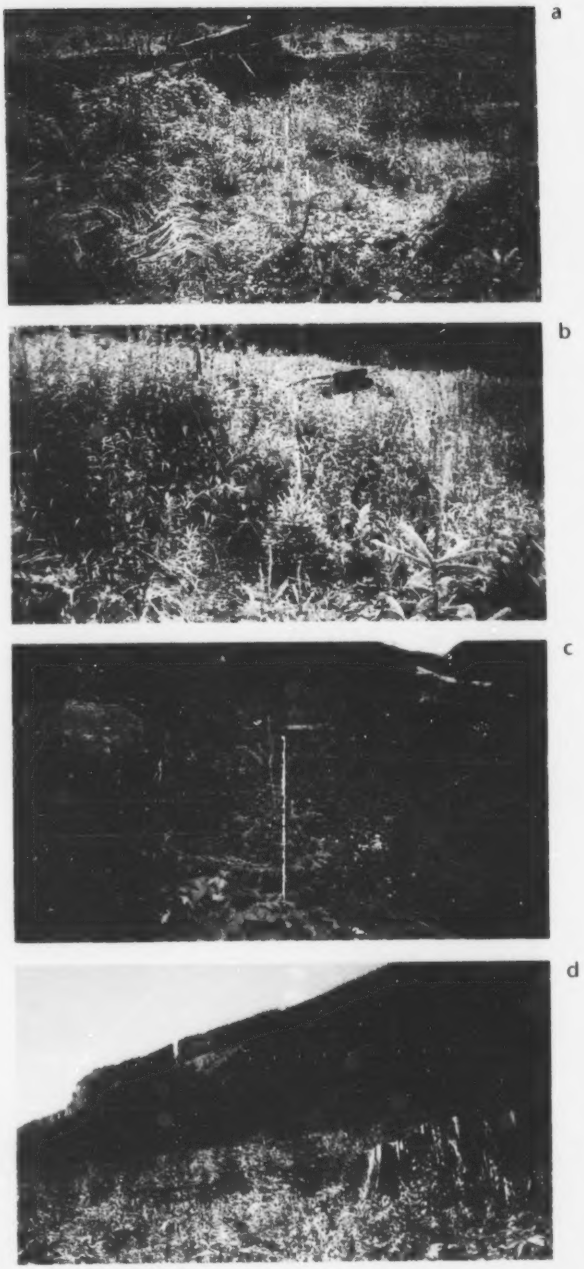


FIGURE 30 *Effects of broadcast aerial glyphosate application on the Fireweed Complex and Engelmann spruce (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Vegetation abundance was reduced by glyphosate for 5 years. Photo credit: JMJ Holdings Inc.*

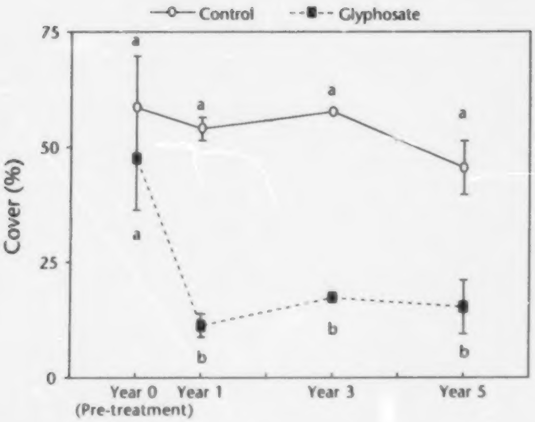


FIGURE 31 *Comparison of mean fireweed cover between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH* Fireweed *Complex. Error bars represent one standard error of the mean (ȳ) which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* ($\alpha = 0.10$).

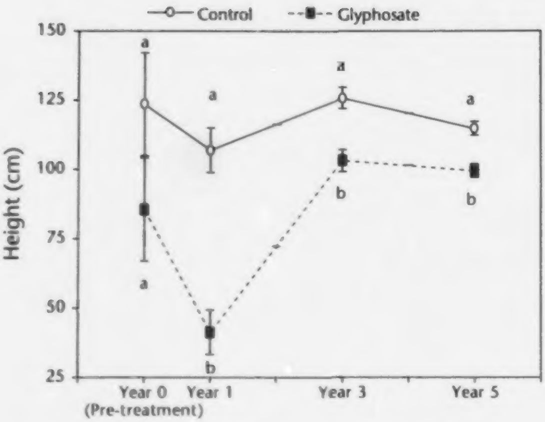


FIGURE 32 *Comparison of mean fireweed height between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH* Fireweed *Complex. Error bars represent one standard error of the mean (ȳ) which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* ($\alpha = 0.10$).

differences in cover did not become significant until year 5 ($p = 0.04$). Shrub height was reduced in years 1 through 5 ($p<0.10$) (Figure 33). Shrub cover and height in the control gradually increased during the 5 years of the study.

Richness and diversity of individual species and structural vegetation groups Brushing the *Fireweed* Complex with glyphosate had no effect on either species richness or diversity ($p>0.10$) (Table 27). Species richness remained relatively constant between the pre-treatment and fifth-year assessments (average 31 species), but there were fluctuations in the presence and relative abundance of individual species. The richness but not the diversity of structural vegetation groups differed between the treatment and control (Table 28). Three years after the application of glyphosate, there was a larger number of vegetation groups in the control than in the treatment, and this difference persisted through year 5 ($p = 0.00$). The greater number of vegetation groups in the control was due to tall broadleaves (trembling aspen) disappearing from the treated plot on one of the sites following glyphosate application.

The application of glyphosate reduced the abundance of several shrub and herb species, while the presence of grasses and purple-leaved willowherb (*Epilobium ciliatum*) tended to increase (Table 29). Fireweed was the main brushing target in this treatment cell, and its cover was substantially reduced by the herbicide on all three sites for 3 years. Pearly everlasting (*Anaphalis margaritacea*) was not abundant on these sites, but its cover was briefly reduced on two of three sites for 1 year following glyphosate treatment. The abundance of two small-stature herbs was also reduced by the herbicide treatment on two of the three sites. Queen's cup (*Clintonia uniflora*) cover was reduced for 1 year on one site and at least 3 years on a second site. Oak fern (*Gymnocarpium dryopteris*) was moderately abundant on two of three sites, and its presence in treated plots was reduced by glyphosate for at least 3 years.

The abundance of four shrubs was also reduced by glyphosate on at least two of the three study sites. Black gooseberry (*Ribes lacustre*) cover decreased over the 3-year monitoring period on two sites, and, on a third site, its minor presence

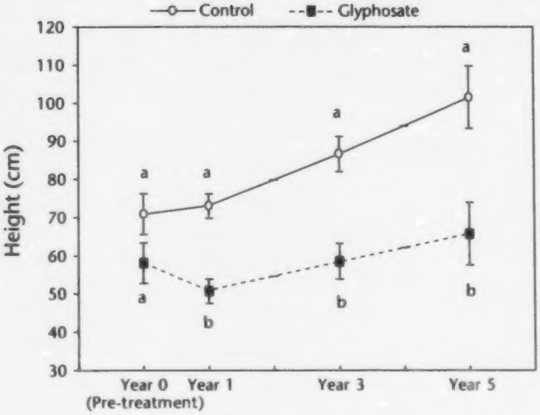


FIGURE 33 *Comparison of mean shrub height between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF/ICH* Fireweed *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\propto = 0.10$).*

in the treated plot disappeared within 1 year of glyphosate application. Sitka mountain ash (*Sorbus sitchensis*) was also present in the low shrub layer on at least two of these sites, and it decreased in abundance in the treated plots for 1 or more years following glyphosate application. White-flowered rhododendron (*Rhododendron albiflorum*) was present on two of the three sites, and on both sites, glyphosate reduced its abundance for at least 3 years. Oval-leaved blueberry (*Vaccinium ovalifolium*) tended to decline on two sites as a result of the glyphosate treatment. Other berry-producing shrubs were inconsistently present on these sites, but their cover was not noticeably reduced by glyphosate.

Sheep and Cattle Grazing

Engelmann spruce in the ESSF zone

This section describes first-year responses of Engelmann spruce seedlings and the ESSF zone *Fireweed* Complex to grazing by sheep and cattle (n = 3) (Figure 34). Seedlings were from 0 (newly planted) to 5 years old at the time of grazing.

TABLE 27 *Richness and diversity of vascular plant species in the ESSF/ICH* Fireweed *Complex before and after glyphosate treatment in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Glyphosate	Control		
Richness				
Pre-treatment	30.33	31.33	2.483	0.80
1 yr post-treatment	25.00	29.00	2.160	0.32
3 yr post-treatment	28.33	32.33	1.080	0.12
5 yr post-treatment	31.00	30.67	1.650	0.90
Shannon-Weaver Diversity Index				
Pre-treatment	2.12	2.13	0.025	0.89
1 yr post-treatment	2.00	1.97	0.094	0.83
3 yr post-treatment	2.18	2.06	0.155	0.63
5 yr post-treatment	2.21	2.11	0.176	0.73
Simpson's Diversity Index				
Pre-treatment	0.79	0.80	0.009	0.60
1 yr post-treatment	0.78	0.75	0.035	0.62
3 yr post-treatment	0.79	0.72	0.049	0.42
5 yr post-treatment	0.81	0.79	0.047	0.42

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 28 *Richness and diversity of structural vegetation groups in the ESSF/ICH* Fireweed *Complex before and after glyphosate treatment in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Glyphosate	Control		
Richness				
Pre-treatment	6.00	6.00	0.000	1.00
1 yr post-treatment	5.33	6.00	0.236	0.18
3 yr post-treatment	5.33	6.33	0.000	0.00*
5 yr post-treatment	5.33	6.33	0.000	0.00*
Shannon-Weaver Diversity Index				
Pre-treatment	1.03	1.01	0.038	0.73
1 yr post-treatment	1.08	0.98	0.055	0.36
3 yr post-treatment	1.02	1.02	0.078	0.97
5 yr post-treatment	1.17	1.02	0.078	0.32
Simpson's Diversity Index				
Pre-treatment	0.57	0.57	0.023	0.91
1 yr post-treatment	0.57	0.52	0.045	0.56
3 yr post-treatment	0.53	0.54	0.039	0.94
5 yr post-treatment	0.60	0.54	0.048	0.43

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 29 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following glyphosate treatment of the ESSF/ICH* Fireweed *Complex in Engelmann spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Low shrubs		*Ribes lacustre* *Sorbus sitchensis* *Rhododendron albiflorum* *Vaccinium ovalifolium*	*Rubus parviflorus*
Herbs	*Epilobium ciliatum* Grass spp.	*Anaphalis margaritacea* *Clintonia uniflora* *Epilobium angustifolium* *Gymnocarpium dryopteris*	*Actaea rubra* *Athyrium filix-femina* *Mitella* spp. *Rubus pedatus* *Smilacina racemosa* *Veratrum viride*

Description of the study sites and treatments

Two of the three study sites are in the Clearwater District of the Kamloops Forest Region, in the Northern Monashee Wet Cold ESSF variant (ESSFwc2). The Otter Creek site is 55 km east of Clearwater and the Patricia Creek site is 25 km northwest of Clearwater. The third site (Scott Road) is in the Arrow District of the Nelson Forest Region, in the Columbia Wet Cold ESSF variant (ESSFwc1). The three sites have variable aspect (north, west, east), but are reasonably similar in slope (20–40%) and elevation (1220–1460 m) (Table 30). All are in mid-slope position. Two of the sites are mesic and one is subhygric, and soils are loamy-textured Podzols and Brunisols.

FIGURE 34 *The* Fireweed *Complex prior to sheep grazing at Scott Road (Site 109) in the ESSFwc1 variant in the Arrow Forest District. Photo credit: JMJ Holdings Inc.*

The sites were logged between 9 and 18 years before PROBE studies were initiated, and on one of the sites there was a 7-year establishment delay between the "pile and burn" site preparation treatment and planting. Another of the sites was broadcast burned 12 years after logging and planted the following year, and the third site (Otter Creek) was grazed as a site preparation treatment prior to planting.

Vegetation was abundant on all three of the study sites prior to grazing, although this was not apparent on one of the sites because of the early pre-treatment assessment date. Average vegetation cover prior to grazing was 82%, and vegetation height was approximately 80 cm. Fireweed dominated the vegetation, with 25–32% cover. Seedling age was variable at the time of brushing; on one site seedlings were newly planted, and, on the other two sites, they were 1 and 5 years old. Almost 70% of seedlings were overtopped prior to grazing, and, again, this estimate would have been higher but for the early assessment date on one site. On two of the sites, it was estimated that virtually all seedlings were in need of release, and vegetation competition was observed to be "heavy" on the third site. Conifer stocking was adequate on the three sites at the time of brushing. Total conifers numbered 1417–2084 stems/ha, of which approximately 850–1000 stems/ha were well spaced.

TABLE 30 *Characteristics and history of the three replicate study sites where the ESSF Fireweed Complex was grazed in Engelmann spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay (years)[a]	Origin[b]	Stock	Age[c] (years)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Otter Creek PROBE 48 Clearwater District	ESSFwc2 07 (subhygric)	1220	W 40%	Podzol/ silt loam	Clearcut 1985 Grazed 1994	9	0	0	P 1994	PSB 415B	0	25 (5)	Fireweed cover: 25 (18) Fireweed height: 94 (18) Lady fern cover: 22 (19) Lady fern height: 96 (23) Thimbleberry cover: 28 (17) Thimbleberry height: 87 (21)	1908	856
Patricia Creek PROBE 73 Clearwater District	ESSFwc2 01 (mesic)	1460	N 20%	Brunisol/ sandy loam	Clearcut 1979 Burned 1991	18	6	1	P 1992	PSB 313B	5	50 (12)	Fireweed cover: 32 (11) Fireweed height: 47 (7)	1417	995
Scott Road PROBE 109 Arrow District	ESSFwc1 03/04 (mesic)	1450	E 35%	Brunisol/ loam	Clearcut 1983 Piled and burned 1984	9	8	7	P 1985, 1991	PSB 415D	1	41 (7)	Fireweed cover: 30 (30) Fireweed height: 138 (17)	2084	993

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 31 *A description of grazing treatments applied to the three replicate study sites to release Engelmann spruce seedlings growing in the ESSF Fireweed Complex*

Site	Initial grazing date	Livestock type	Grazing effect	Repeat grazing
Otter Creek	July 1994 (site prep.) and late June 1995	Cattle	Vegetation reduced to ground level by browsing and trampling	None
Patricia Creek	late June 1997	Sheep	Treatment specs adhered to	None
Scott Road	Mid-August 1992	Sheep	Unknown	None

The Otter Creek site was grazed by cattle and the other two sites were grazed by sheep, but all three sites received only a single grazing pass for purposes of brushing (Table 31). However, the Otter Creek site was also grazed once by cattle, in late June 1994, as a site preparation treatment. Grazing treatments for conifer release were applied from late June to mid-August. We recognize the potential for sheep- and cattle-grazing effects to be different, and hope to be able to analyze them separately in the future. At present, inspection of the data suggested that the effects on vegetation, at least, were similar enough to include the three sites in a single treatment cell.

Conifer response

Survival and vigour One year after grazing, mean survival of 1- to 6-year-old Engelmann spruce seedlings (0–5 years old at the time of treatment) was 94%, and there were no differences between the treatment and control ($p>0.10$) (Table 32). All mortality was attributed to competing vegetation. However, overall seedling vigour was reduced within a year of brushing in both the treatment and control (Figure 35). Prior to grazing, 46% of seedlings were of good vigour, 31% were moderate, and 23% were poor. One year later, only 14% of grazed seedlings were of good vigour, 51% were moderate, and 35% were poor. Similarly, in the control, only 7% of seedlings continued to be of good vigour, 61% were moderate, and 32% were poor. Seedlings in the control were affected mainly by competing vegetation, whereas those in the treatment were damaged primarily by livestock. Cattle damaged 56% of seedlings on the Otter Creek site, but sheep caused no damage to the 1- and 5-year-old seedlings on the other two sites.

TABLE 32 *Survival and growth responses of Engelmann spruce seedlings to grazing in the ESSF Fireweed Complex*

Response variable	Means: Grazing	Means: Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	93	95	3.401	0.62
Stem diameter (cm)				
Pre-treatment	0.75	0.79	0.024	0.34
1 yr post-treatment	1.08	1.08	0.030	0.96
Diameter increment (cm)				
1 yr post-treatment	0.34	0.31	0.013	0.29
Height (cm)				
Pre-treatment	38.3	38.9	1.188	0.75
1 yr post-treatment	47.5	45.3	4.149	0.74
Leader length (cm)				
Pre-treatment	14.5	13.5	1.191	0.60
1 yr post-treatment	8.5	9.7	1.098	0.51
Height:diameter ratio				
Pre-treatment	54.0	53.8	1.774	0.94
1 yr post-treatment	47.5	47.0	6.051	0.97

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

Growth One year after grazing by cattle and sheep, there were no significant differences in Engelmann spruce seedling stem diameter, diameter increment, height, leader length, or height:diameter

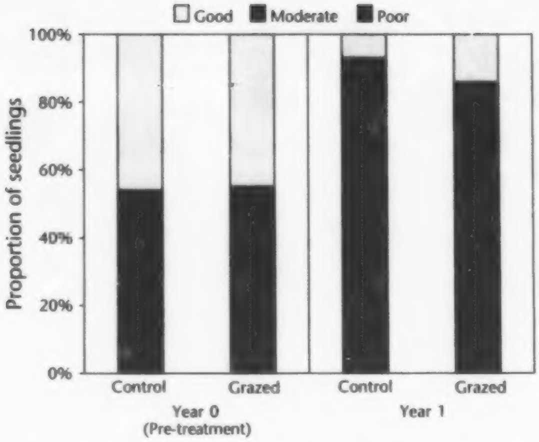


FIGURE 35 *Comparison of Engelmann spruce vigour between the grazing treatment and control before and 1 year after treatment of the ESSF Fireweed Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

ratio between the treatment and control ($p>0.10$) (Table 32). Prior to grazing, seedlings averaged 38.6 cm tall, with 0.77-cm stem diameters. One year later, they were 46.4 cm tall, with 1.08-cm stem diameters.

Standardized distributions of spruce stem diameter and height (Figures 36 and 37) confirm the lack of seedling response to grazing. Prior to grazing, distributions for diameter and height were approximately normal, and were similar in the treatment and control. They changed very little within the first year post-treatment.

Competitive status Grazing caused immediate reductions in abundance of the *Fireweed* Complex, but the effects on spruce seedling competitive status had disappeared within a single season (Figure 38). Twenty-six percent of seedlings were considered free of surrounding vegetation prior to grazing, largely because of the early assessment date on at least one site. One year later, only 4% of seedlings in the grazing treatment, and none of the control seedlings, were free of vegetation. Prior to grazing, 68% of seedlings were overtopped, and

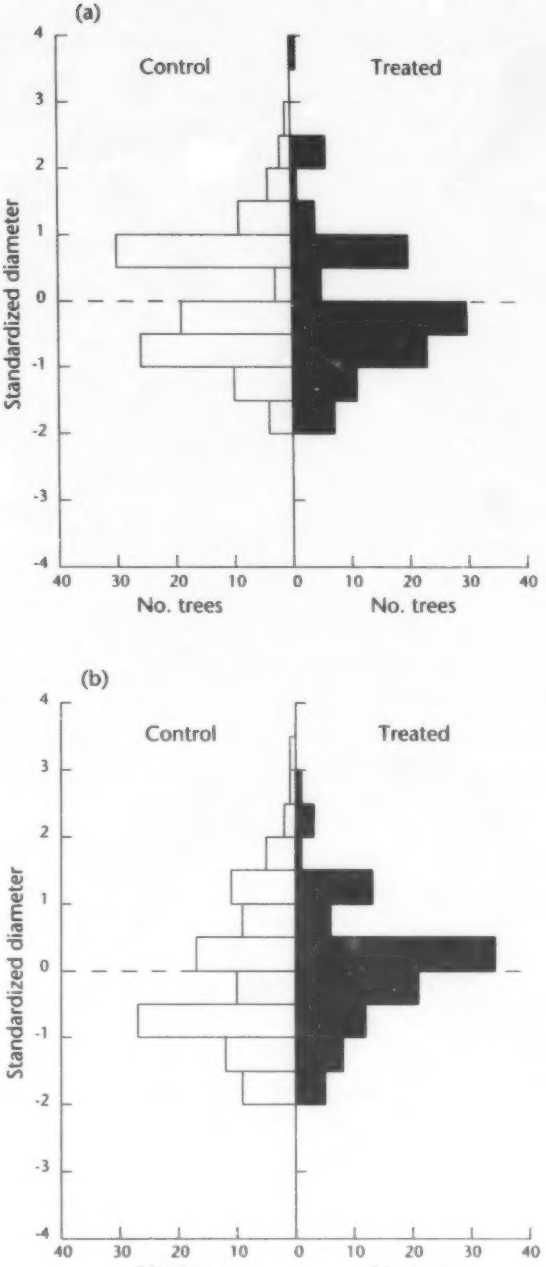


FIGURE 36 *Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; s.d. $= 1$; $n = 3$ for the control and treatment combined) for Engelmann spruce in the ESSF Fireweed Complex before and after livestock grazing. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment.*

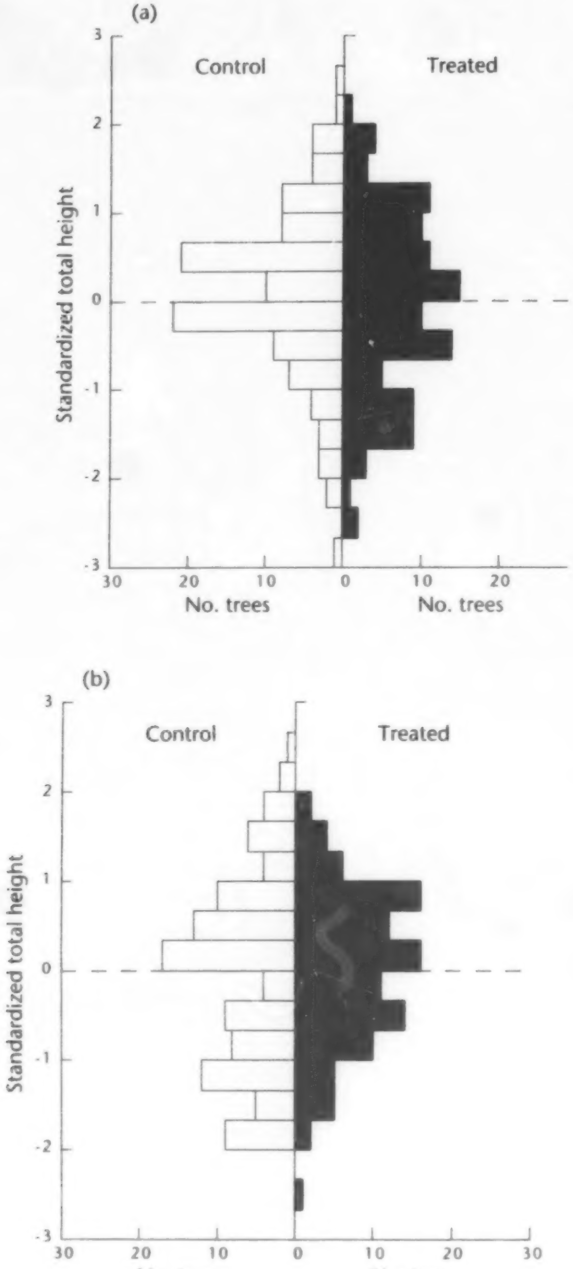


FIGURE 37 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Engelmann spruce in the ESSF/ICH* Fireweed *Complex before and after livestock grazing. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment.*

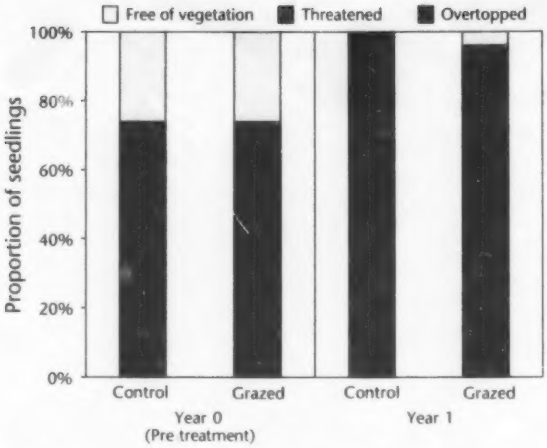


FIGURE 38 *Comparison of Engelmann spruce competitive status between the grazing treatment and control before and 1 year after treatment of the ESSF* Fireweed *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

1 year later this had increased to 73% in the treatment and 86% in the control.

Plant community response

Abundance One year after grazing, there were no significant differences in height or cover of fireweed, overall vegetation, or the shrub layer (p>0.10) (Table 33). Herb cover was also unaffected by grazing, but herb height was reduced in comparison to the control (102.5 cm in the control versus 54.2 cm in the grazing treatment, p = 0.08). In spite of the lack of significant effects on vegetation abundance as a result of grazing, there was variation between sites. For example, vegetation at the Scott Road site was dramatically reduced for 1 year, but had completely recovered after 3 years (Figure 39).

Richness and diversity of individual species and structural vegetation groups Sheep and cattle grazing of the *Fireweed* Complex had no effect on either species richness or species diversity (p>0.10) (Table 34). Species richness increased slightly between the pre-treatment assessment (30 species)

TABLE 33 *Cover and height of vegetation in the ESSF Fireweed Complex before and after grazing in Engelmann spruce plantations*

	Means		Standard	
Response variable	Grazing	Control	error	p-value
Fireweed				
Cover (%)				
Pre-treatment	21.4	36.8	13.616	0.51
1 yr post-treatment	34.7	52.0	12.086	0.42
Height (cm)				
Pre-treatment	91.1	95.1	7.737	0.75
1 yr post-treatment	74.2	116.3	20.926	0.29
All vegetation				
Cover (%)				
Pre-treatment	82.0	81.0	3.818	0.87
1 yr post-treatment	81.5	92.0	4.216	0.22
Height (cm)				
Pre-treatment	70.5	86.7	18.611	0.60
1 yr post-treatment	74.6	105.5	12.888	0.23
Herbs				
Cover (%)				
Pre-treatment	69.9	66.5	2.471	0.43
1 yr post-treatment	66.2	74.1	4.659	0.35
Height (cm)				
Pre-treatment	62.3	85.1	21.058	0.52
1 yr post-treatment	54.2	102.5	9.956	0.08*
Shrubs				
Cover (%)				
Pre-treatment	17.2	21.2	4.133	0.57
1 yr post-treatment	21.4	25.4	1.948	0.29
Height (cm)				
Pre-treatment	102.5	85.1	9.178	0.31
1 yr post-treatment	82.3	82.3	11.166	1.00

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 34 *Richness and diversity of vascular plant species in the ESSF Fireweed Complex before and after grazing in Engelmann spruce plantations*

	Means		Standard	
Response variable	Grazing	Control	error	p-value
Richness				
Pre-treatment	29.67	30.67	2.550	0.81
1 yr post-treatment	31.67	32.00	0.850	0.81
Shannon-Weaver Diversity Index				
Pre-treatment	2.13	2.09	0.045	0.63
1 yr post-treatment	2.33	2.23	0.029	0.13
Simpson's Diversity Index				
Pre-treatment	0.81	0.80	0.006	0.41
1 yr post-treatment	0.84	0.81	0.010	0.15

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

and the first-year assessment (32 species), but the increase was found equally in the treatment and the control. As with individual species, there were no significant differences in the richness of structural vegetation groups (p>0.10) (Table 35), but the diversity of groups in year 1 was marginally higher in the grazing treatment than in the control according to Simpson's Diversity Index (p = 0.10).

One year after the *Fireweed* Complex was grazed by sheep and cattle, there were no trends of increasing or decreasing abundance of individual herb or shrub species (Table 36). Even preferred forages such as fireweed and grass were not reduced in abundance following the grazing treatments. Berry-producing shrubs, which are an important wildlife food, were also unaffected by sheep and cattle grazing.

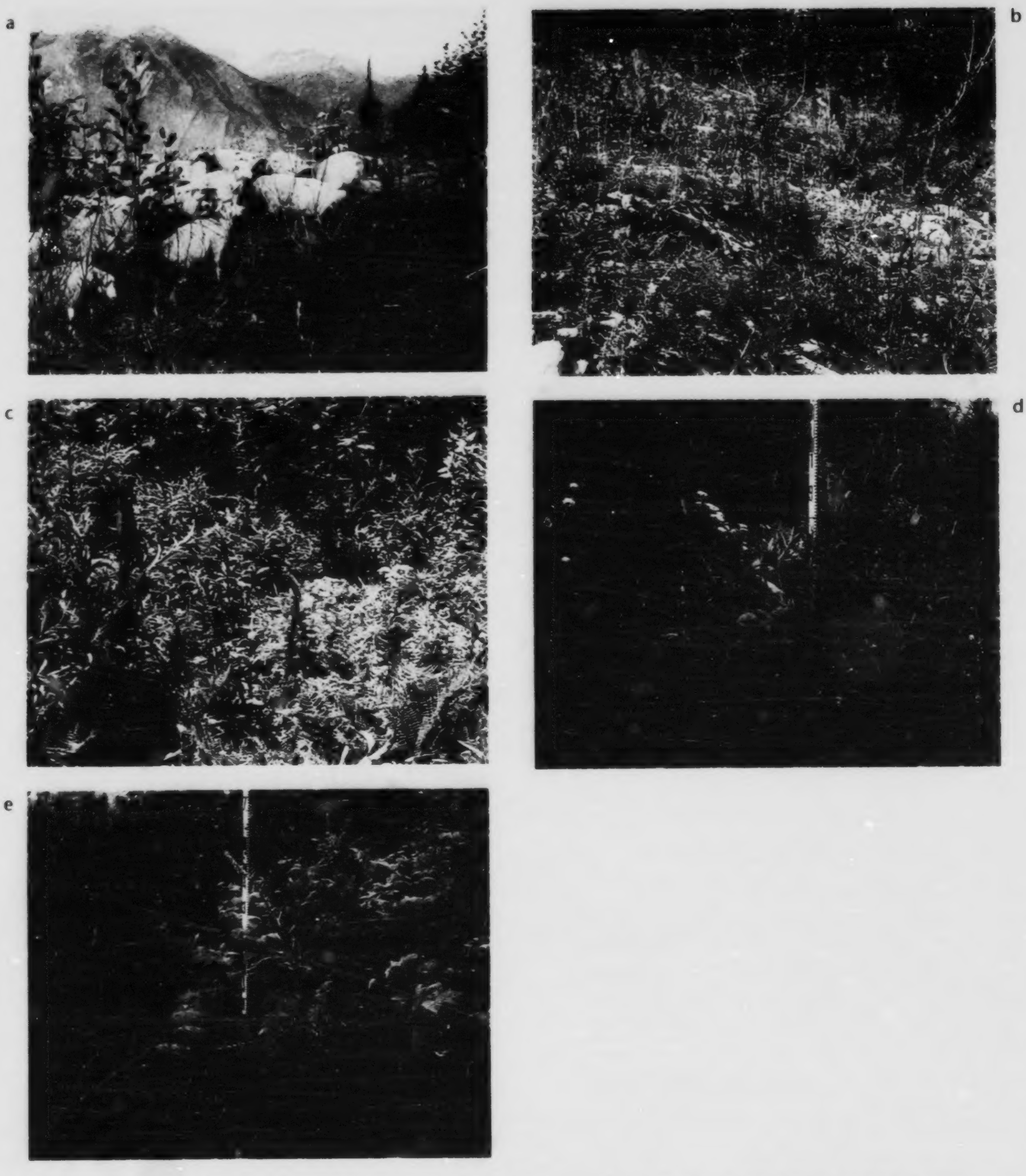


FIGURE 39 *Effect of sheep grazing on the* Fireweed Complex *(a) immediately, (b) 1 year, (c) 3 years, and (d) 5 years following treatment. The control (e) is shown 5 years post-treatment for comparison. The plant community at Scott Road had recovered to control levels by 3 years post-treatment.* Note: *Although the photo shows fifth-year responses, we report statistical results for only 1 year because not all replicate sites had been measured for 5 years. Photo credit: JMJ Holdings Inc.*

TABLE 35 *Richness and diversity of structural vegetation groups in the ESSF* Fireweed *Complex before and after grazing in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Grazing	Control		
Richness				
Pre-treatment	5.67	5.00	0.236	0.18
1 yr post-treatment	5.33	5.33	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.10	1.07	0.019	0.31
1 yr post-treatment	1.19	1.13	0.028	0.25
Simpson's Diversity Index				
Pre-treatment	0.59	0.59	0.023	0.99
1 yr post-treatment	0.63	0.60	0.009	0.10*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 36 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following grazing in the ESSF* Fireweed *Complex in Engelmann spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Low shrubs			*Oplopanax horridus*
			Ribes lacustre
			Rubus idaeus
			Sambucus racemosa
			Vaccinium membranaceum
Herbs			*Anaphalis margaritacea*
			Circaea alpina
			Epilobium angustifolium
			Grass spp.
			Mitella spp.
			Tiarella trifoliata

In southern interior British Columbia, the widespread *Fireweed* Complex is brushed to increase the availability of light to seedlings and to prevent physical damage from snow- and vegetation-press. Manual and chemical brushing are the most common treatments, but grazing is also considered a useful technique in some areas. At present, there is sufficient replication of PROBE installations on fireweed-dominated sites to discuss the responses of Engelmann spruce and lodgepole pine seedlings to manual cutting in the ESSF and ICH zones, of Engelmann spruce seedlings to glyphosate application in the ESSF zone, and of Engelmann spruce seedlings to grazing in the ESSF zone.

Manual Cutting

Conifer response

Manual cutting in a 0.5- to 1.0-m radius around seedlings had no lasting effects on abundance of the *Fireweed* Complex in either the ESSF or ICH zones, and it did not result in significant improvements in survival or growth of Engelmann spruce or lodgepole pine seedlings. Survival was excellent among spruce in ESSF (and higher-elevation ICH) zones (96% after 3 years) and good among pine in the ICH zone (88% after 5 years). Jobidon and Charette (1997) similarly found that black spruce (*Picea mariana*) survival was not improved by manual treatment of a fireweed community in Quebec, but in that study seedling stem diameter and height increased in response to the brushing treatment. In our study, competing vegetation was identified as the primary cause of mortality among ICH pine in both the manual cutting treatment and control, but the low mortality of spruce in the ESSF/ICH zones was due to a variety of other factors. On one site, spruce sustained considerable damage during the cutting treatment, which is consistent with other studies citing physical damage during manual cutting as an important cause of mortality (e.g., Hart and Comeau 1992; Whitehead and Harper 1998).

The lack of response of both vegetation and conifer seedlings to a single manual cutting treatment observed in this study is supported by other, longer-term trials in British Columbia. For instance, an ICH vegetation community dominated by thimbleberry, raspberry, and fireweed was minimally affected by manual cutting, and there was no response among Engelmann spruce seedlings over a period of 10 years (Whitehead and Harper 1998). Similarly, on a fireweed- and shrub-dominated site in the ESSF, manual cutting had a short-lived effect on vegetation, and produced no lasting improvements in seedling growth (Harper et al. 1997). Comeau et al. (2000a) concluded that a single cutting treatment was of little benefit to Engelmann spruce seedlings, but cutting two or three times could improve stem diameter. If cutting took place in summer rather than spring, height was also improved. In contrast, Jobidon and Charette (1997) found that 10 years after a single manual cutting treatment, black spruce seedlings growing among a fireweed and raspberry complex in Quebec had 24% larger stem diameters and were 12% taller than seedlings in an untreated control. Repeated brushing treatments in subsequent years did not increase seedling response in that study. This contradicts the conclusions of Wagner et al. (1999), who found that keeping black spruce continually free of competing vegetation for 1–3 years after planting was required to improve seedling growth.

In our study, manual cutting treatments were applied in July to mid-August, suggesting that the objectives of brushing were primarily to reduce the physical effects of snow- and vegetation-press and secondarily to increase light availability to seedlings. The lack of treatment effects on seedling survival and growth, as well as on vegetation, suggest that these objectives may not have been achieved. However, untreated spruce, which were 5–7 years old at the time of the third-year assessment, were increasing in height at an annual rate of 15.4 cm, which is acceptable according to Vyse (1981), and increasing in stem diameter at an annual rate of 0.41 cm. Untreated lodgepole pine, which were 6–8 years old at the time of the fifth-year assessment, averaged 181.2 cm tall and were increasing in height at 38.4 cm/yr, which is similar to average growth rates reported by Vyse and Navratil (1985). They were increasing in stem diameter at 0.78 cm/yr.

Plant community response

Manual cutting of the *Fireweed* Complex had only a short-lived effect on its abundance, so that within

1 year of cutting there were no significant differences between the treatment and control in the abundance of fireweed, the herb layer, or overall vegetation. In our study, about three-quarters of all sites received only a single manual cutting treatment. Repeated treatments were applied on only two sites, but again, they appeared to have little effect on the plant community. Unfortunately, replication of sites with repeated treatments was insufficient to test for related seedling performance effects. The timing of manual treatments varied from early July to October in our study, depending on whether the brushing objective was to increase light availability (mid-summer treatments) or reduce the effects of snow- and vegetation-press (late summer/fall treatments). Rapid recovery of the *Fireweed* Complex makes it difficult to accomplish both objectives with a single cutting treatment. Between-site variability in height and cover of fireweed tended not to increase dramatically following treatment, suggesting that differences in cutting date had little effect on the ability of this complex to recover.

Manual treatment of the *Fireweed* Complex did not change the richness or diversity of either individual plant species or structural vegetation groups in the ICH and ESSF zones. Neither did manual cutting reduce the abundance of berry-producing shrubs such as red raspberry, thimbleberry, elderberry, black huckleberry, and black gooseberry, which is an important consideration for wildlife habitat management.

Glyphosate

Conifer response

Brushing with glyphosate reduced the abundance of fireweed and overall vegetation for at least 5 years; however, this had no effect on survival of Engelmann spruce seedlings (average 91%), and only a minor effect on seedling growth. Spruce height:diameter ratio was reduced in the treatment relative to the control in years 1 through 5, but even the control H:D was below 50 (46.9 in year 5). Otherwise, there were no other consistent growth responses as a result of glyphosate application. Differences in spruce seedling stem diameter were marginally significant in year 3 (1.75 cm in the treatment versus 1.43 cm in the control, $p = 0.09$) and marginally insignificant in year 5 (2.80 cm in the treatment versus 2.06 cm in the control, $p = 0.11$). Stem diameter commonly responds to brushing before height (Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c), but further study is required to determine whether early differences in stem diameter will translate into significant size differences over the long term. In other studies, spruce seedlings treated with glyphosate had at least 20% (0.9–1.4 cm) greater stem diameter and were 13–18% (26–38 cm) taller than control seedlings after a decade (Harper et al. 1997; Whitehead and Harper 1998).

Five years after glyphosate application, spruce seedlings in our study had not increased in height. Engelmann spruce and Douglas-fir seedlings have been known to exhibit a negative height response following brushing with glyphosate (e.g., Harper et al. 1997; Mather and Simard 1998j), suggesting that they may be negatively affected by the herbicide, even when it is applied within the recommended treatment window (Lloyd and Heineman 1994a). An alternative explanation is that the reductions in height growth were a physiological response to the sudden increase in light. According to Chen (1997), both Engelmann spruce and Douglas-fir are plastic in their ability to allocate resources to shoot or root growth, and, under low light conditions, shoot growth is favoured. It is possible that the increase in light availability following glyphosate treatment stimulated a predominance of root growth over shoot growth until a favourable root:shoot ratio was achieved.

Plant community response

Ground foliar application of glyphosate at 1.4–2.1 kg ai/ha in mid- to late August significantly reduced height and cover of fireweed for at least 5 years. This is consistent with other reports on glyphosate efficacy for treating fireweed (e.g., Expert Committee on Weeds 1987; Newsome 1992; Lloyd and Heineman 1994a). The herbicide treatment also reduced height and cover of the herb layer for 1 year, and overall vegetation cover for 5 years. Shrubs were a relatively minor vegetation component at the start of this study, and the effects of glyphosate application were not immediately obvious. However, by year 5, it was apparent that glyphosate had slowed the increase in shrub abundance, so that shrubs occupied only half as much cover as in the control, and were only two-thirds as tall.

Neither species richness nor species diversity were affected by brushing the ESSF *Fireweed* Complex with glyphosate. However, several species decreased in abundance following glyphosate application, particularly in the first year after treatment. Fireweed was the main brushing target and it was reduced in abundance for at least 5 years. Several berry-producing shrubs (oval-leaved blueberry, black gooseberry, and Sitka mountain-ash) were also reduced during the 5-year monitoring period, which may have implications for the availability of food for wildlife. The abundance of purple-leaved willowherb and grasses increased following glyphosate application, likely because of greater light availability. Although some grasses compete strongly for light as they increase in cover (Lieffers and Stadt 1994), we have not observed these communities to be common in the southern interior.

Sheep and Cattle Grazing

Conifer response

A single grazing pass by sheep or cattle had little effect on abundance of the *Fireweed* Complex in the ESSF zone, and, within 1 year, had not improved survival or growth among Engelmann spruce seedlings (newly planted to 6 years old at the time of grazing). Caution should be taken in interpreting these results, however, since the wide variability in age and time since establishment on these sites could reduce significance of the growth and survival responses. In addition, we currently have only 1 year of data, which reduces our ability to extrapolate these results. One year after grazing, 94% of seedlings survived, but vigour was considerably reduced by competing vegetation in both the treatment and control, as well as by cattle trampling in the grazed portion of one of the study sites. The vigour reductions suggest that there will be further mortality in both the treatment and control. Although grazing by sheep and cattle were analyzed together in our study, cattle damaged far more seedlings by trampling than did sheep. Neither sheep nor cattle browsed the Engelmann spruce seedlings.

Only first-year results are currently available for our study, but the effects of grazing on the vegetation community were minor and short-lived, and conifers are not expected to respond over the longer term. It is commonly accepted that more than one grazing pass is required to release conifer seedlings growing among vigorous herbaceous vegetation (Newsome et al. 1995). However, seedling responses may also be minor if competition for resources is not serious. For instance, Newsome (1996) found that increases in seedling growth were smaller than anticipated after grazing had reduced the abundance of an ICH zone *Fireweed* Complex, and concluded that vegetation competition had not been as severe as originally thought (Newsome 1996).

Plant community response

Height of the herb layer was reduced in relation to the control 1 year after the *Fireweed* Complex was grazed by cattle or sheep. However, there were no significant reductions in the abundance of either fireweed or total vegetation. These results support recommendations by Newsome et al. (1995), that two to three seasons of sheep grazing are required to reduce the abundance of vegetation sufficiently to release seedlings. In the ICH zone of the Cariboo Forest Region, three grazing passes have had an effect on vegetation that was comparable to a single application of glyphosate (Newsome 1996).

Grazing affects herbaceous vegetation similarly to manual cutting in that animals clip off shoots; however, grazing appears to be more specific in its effects on particular plant species. For instance, fireweed is a preferred forage for sheep, and repeated grazings can reduce its abundance, allowing less competitive species to gain dominance. In one study, low-stature species such as bunchberry (*Cornus canadensis*) increased in abundance as fireweed decreased (Newsome et al. 1995). The authors suggest that potential species shifts be considered before grazing is prescribed, since they may not always favour seedling performance.

Effects of the Community on Resource Availability

The *Fireweed* Complex is an important early seral vegetation community throughout much of the southern interior. It contributes organic matter to disturbed sites and may also retard the development of more competitive shrub communities. However, the *Fireweed* Complex can occur at high densities and have negative effects on conifer seedling performance, particularly on subhygric and wetter sites (Lindeburgh 1995) in the ICH and ESSF zones. Competition for light and the physical effects of snow- and vegetation-press are the most significant factors on most sites, but the effects of dense vegetation on the soil thermal regime are also important at higher elevations (Balisky and Burton 1995). Competition for soil water and nutrients is considered of little consequence on most southern interior sites dominated by this complex.

Fireweed is a particularly strong competitor for light because its canopy develops earlier in the growing season than many other species. For example, a dense fireweed community reduced the amount of photosynthetically active radiation reaching seedlings to about 20% of above-canopy radiation by mid-June, whereas thimbleberry and lady fern canopies did not have such a profound effect until about 3 weeks later (Spittlehouse and Stathers 1990; DeLong 1991). The light saturation point for interior spruce in British Columbia is approximately 600 µmol m^2s^{-1}, which is usually reached at about one-quarter to one-half of full sunlight on a clear day (Coates et al. 1994). Although spruce seedlings can survive in heavy shade, they become spindly (Binder et al. 1987), and are increasingly susceptible to physical injury from snow- and vegetation-press. In our study, fireweed abundance was apparently too low to reduce seedling survival or to reduce growth rates to unacceptable levels. Manual cutting took place between early July and mid-August, and vegetation had fully recovered by the following growing season. This implies that the amount of light reaching seedlings increased for only the late part of a single growing season, and helps explain the lack of seedling growth response. In contrast, glyphosate significantly reduced fireweed abundance for at least 5 years, which presumably increased light availability throughout that period.

In addition to reducing the availability of light, a dense vegetation canopy restricts soil and air warming in the seedling microenvironment. In colder environments, such as in the ESSF zone, management of thermal regimes is a particularly important consideration (Farnden 1994). Abundant research has shown that the physiological functioning of spruce is inhibited at low soil temperatures (e.g., Carter et al. 1988; Grossnickle 1988; Örlander et al. 1990), and Coates et al. (1994) suggest that increasing soil temperatures above a soil temperature threshold of 7–8°C is a priority for managing spruce plantations. Manipulation of vegetation structure and composition can alter the soil thermal regime to some extent, but in field studies it is difficult to know whether seedlings are responding primarily to improved soil thermal regime, increased light availability, warmer air temperatures, or some combination of factors (A. Vyse, pers. comm., 2000). However, the effects of brushing on soil temperature are likely most critical on sites with harsher environments than those dominated by the *Fireweed* Complex. For instance, complete removal of vegetation and forest floor material increased soil temperature and improved seedling growth on a high-elevation (1550 m) ESSF site dominated by ericaceous shrubs (Coates et al. 1991), but, on a lower-elevation (1150 m) ICH site with dense fireweed cover, Stathers (1994) found little difference in root zone temperature between the control and a glyphosate treatment. Brushing is far less effective than many mechanical site preparation techniques as a tool for altering soil thermal regime (Spittlehouse and Stathers 1990), but not all ESSF sites require such radical treatment. Soil temperature data were not collected in our study, but significant reductions in vegetation abundance for 1–3 years following glyphosate application in the ESSF zone may have marginally improved soil temperature regime as well as increased the availability of light to seedlings. Newsome et al. (2001, in review) found that soil temperature increased as a result of applying glyphosate to a herb-dominated community in the ESSF for purposes of site preparation.

Manipulation of the vegetation canopy can affect the occurrence of summer frost injury, but, in our study, no seedling frost damage was recorded in either the treatment or the control. Low vegetation canopies have a variable effect on the occurrence of frost injury; in some cases they improve the temperature at seedling height by restricting radiative heat loss from the ground and in other cases they restrict air mixing, which exacerbates the potential for frost damage (Stathers 1989). Our study sites, however, tended to have at least moderate slopes, which would have stimulated the downslope movement of cold air and reduced the potential for frost damage. On an ICH site, Stathers (1994) found that minimum daily air temperatures at seedling height were approximately 1°C warmer under a dense fireweed canopy than where vegetation had been removed with glyphosate.

Competition Thresholds

The competition thresholds for stem diameter of 0- to 5-year-old Engelmann spruce in the ESSF and ICH zones, and for 0- to 5-year-old lodgepole pine in the ICH zone (where fireweed cover was used as a competition index), were 36, 46, and 40% cover, respectively. Where CRH (fireweed cover * fireweed modal height)/conifer modal height was used as an index, the thresholds were 49, 60, and 49 for ESSF spruce, ICH spruce, and ICH pine, respectively. Above the thresholds, fireweed competition appeared to be the most important factor limiting tree growth, setting the upper limit for spruce and pine diameter. Below the thresholds, stem diameter was highly variable among both treated and control trees, probably because trees were constrained more by factors such as genetics, microsite or damaging agents than by fireweed competition. Reducing neighbouring fireweed abundance to values below the thresholds should increase conifer growth rates. Trees below the thresholds should maintain good but variable growth rates without treatment, and further reductions in fireweed abundance are not expected to improve their growth predictably.

The fireweed cover and CRH thresholds suggest that Engelmann spruce tolerated slightly higher levels of fireweed competition in the ICH than in the ESSF zone. Better growing conditions due to warmer temperatures, a longer growing season, and possibly greater soil resource availability may allow spruce to compete more effectively with fireweed at lower elevations. In other words, spruce may maintain diameter growth rates at slightly lower light levels in the ICH than in the ESSF zone because resources are more readily available over a longer growing season. Nevertheless, warmer summers in the ICH zone are also associated with more frequent drought stress than in the ESSF zone. Other studies have shown that diameter and height growth vary with both light availability and climatic region (Wright et al. 1998). Juvenile hybrid spruce in a moist temperate (ICH) climate, for example, achieved 51% of maximum diameter growth (diameter growth in full sunlight) at 25% of full sunlight, whereas hybrid spruce in a transitional subalpine (ESSF) climate achieved only 21% of maximum diameter growth at that light intensity (Wright et al. 1998). Reductions in light had less effect on height than on diameter growth, and there was less effect on height in the subalpine than in the moist temperate climate. Those authors suggest that the patterns among climatic regions are correlated with temperature but they may also be causally related to other environmental factors. Their results support our finding that spruce tolerates slightly higher fireweed levels, and likely lower light levels, in the ICH than in the ESSF zone.

The lower cover and CRH thresholds in the ESSF than in the ICH zone may also have resulted from growth-inhibiting temperatures and a shorter growing season at the higher-elevation sites. Air temperatures that drop below 14°C have been associated with lower rates of net photosynthesis, stomatal conductance, and diameter growth (Dykstra 1974; Running 1980; Coates et al. 1991), and growing season frost damage can also occur on sites where cold air pools and dense vegetation restricts air mixing at seedling height. Frost damage was not observed on our ESSF sites, but it is known to be more problematic on ESSF than on ICH sites that are both dominated by fireweed (Stathers 1989, 1994). In the Cariboo Forest Region, T. Newsome (pers. comm., 2000) reports that frost damage is rare on fireweed-dominated sites in the ESSF zone, and is much less of a growth-inhibiting factor than the effects of low air temperature and short growing season.

Lodgepole pine had slightly lower fireweed cover and CRH thresholds than Engelmann spruce in the ICH zone. Traditionally, lodgepole pine has been ranked as more shade intolerant than spruce (Krajina et al. 1982), which may explain its slightly lower tolerance of overtopping fireweed. A recent study in the ICH zone, however, showed considerable variability and overlap in growth rates of lodgepole pine and hybrid spruce at moderate light levels (30–70% full sunlight) (Coates and Burton 1999), which probably encompass the light levels under the fireweed thresholds identified in this study. This may help explain why the differences between our pine and spruce fireweed thresholds were very small. At high levels (>70% full sunlight), Wright et al. (1998) and Coates and Burton (1999) have shown that growth responses of lodgepole pine were greater than those of hybrid spruce. Their results imply that, although pine may outgrow spruce under high light conditions (such as when fireweed abundance is dramatically reduced), the two tree species are likely to grow at similar rates under intermediate light conditions (such as when fireweed abundance is reduced to the moderate threshold levels identified in this study).

When fireweed densities are very high, brushing may be more critical for survival of lodgepole pine than of spruce. Kobe and Coates (1997) showed, for example, that 5-year survivorship of lodgepole pine (<10%) was considerably lower than that of hybrid spruce (approximately 30%) at very low light levels (5% full sunlight). In our study, survival of spruce (98%) and pine (90%) was excellent, except on one lodgepole pine site where dense fireweed was associated with high seedling mortality. These results indicate that fireweed densities were too low on most sites to reduce light below compensation levels.

Competition thresholds have not previously been identified for the *Fireweed* Complex. However, DeLong (1991) found that low to moderate cover of fireweed did not greatly reduce the photosynthetic potential of white spruce seedlings, whereas a dense canopy reduced it by more than 75%. The thresholds identified in our study are below the fireweed covers where DeLong (1991) found reductions in spruce photosynthesis. Based on the study of Coates and Burton (1999), it is possible that spruce and especially pine may respond to further reductions in fireweed cover below our thresholds. However, neither spruce nor pine growth increased significantly in response to glyphosate or manual treatments, in spite of long-term fireweed reductions following the glyphosate treatment. In addition, only 3–5% of treated spruce and pine that were growing in neighbourhoods below the fireweed thresholds achieved ≥80% of the maximum growth measured on the sites, indicating that growth of most trees remained limited by factors other than fireweed competition. In the case of manual cutting, rapid recovery of the fireweed may also have slowed conifer growth. These results indicate that there is a need to experimentally test competition thresholds derived from individual tree measurements, particularly the levels and period over which thresholds must be maintained.

Competition thresholds often define levels of vegetation that affect conifer seedling growth rather than short-term survival. However, survival is a critical issue for operational silviculturists, and criteria for identifying sites at risk would be useful. Lindeburgh (1995) identified soil moisture regime as an important factor in the ICHmw2, since survival tended to be reduced by the dense fireweed stands that develop on subhygric to hygric sites, but not by the moderately dense stands that develop on mesic sites. In that study, most seedling mortality occurred when seedlings were very young, implying that brushing of high-risk sites should occur promptly after planting. The time span between logging or site preparation and planting is likely also important. Most PROBE sites had been planted within 1–2 years of site preparation, so that seedlings were established before the *Fireweed* Complex was fully developed. There is also evidence that early survival of moderately shade tolerant species such as Engelmann spruce and interior Douglas-fir is not determined by light availability alone (Chen 1997), and that physical damage probably also contributed to mortality on our sites.

Effectiveness of Treatments at Meeting Management Objectives

One of the common operational objectives of brushing, in addition to improving conifer performance, is to assist seedlings in meeting height and stocking requirements for free-growing, as specified by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). On our ESSF study sites, the Code and Guidelines specify that target stocking is 1200 (minimum 700) well-spaced stems/ha, and within 15–20 years of establishment, spruce must be a minimum of 0.8 m tall and pine a minimum of 1.6 m tall, and seedlings must be 100% as tall as surrounding vegetation. On our ICH sites, they specify that target stocking is 1200 (minimum 700) well-spaced stems/ha, and within 9–15 years of establishment, spruce must be a minimum of 1.0 m tall and pine a minimum of 2.0 m tall, and seedlings must be 100% as tall as surrounding vegetation.

In our study, untreated spruce (6–7 years old at the time of the third-year assessment) and pine (6–8 years old at the time of the fifth-year assessment) were increasing in height at the same rate as seedlings in the manual cutting treatments. Spruce in the manual cutting treatment averaged 96% as tall as the overall vegetation height, and control seedlings averaged 101% as tall. Average seedling height in both the treatment and control was only slightly below the minimum height requirement for the ICH (1.0 m), and, at current growth rates, we predict the conifer:vegetation height ratio requirements will be met in both treatment and control at approximately the same time (about 4 years after manual cutting was applied) (Figure 40). Spruce seedlings are therefore predicted to meet free-growing criteria when they are 6–8 years old, on average, which is earlier than both the ICH and ESSF early free-growing assessment age. Lodgepole pine in both the manual cutting treatment and control averaged slightly more than twice as tall as the overall vegetation height in the fifth-year assessement. At the growth rates measured in year five, both treated and control seedlings were expected (on average) to meet the minimum height of 2.0 m by year 6 after brushing, when they were 7–9 years-old (Figure 41). According to the year-5 silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), an average 474 stems/ha met free-growing requirements, with no significant differences between the treatment and control.

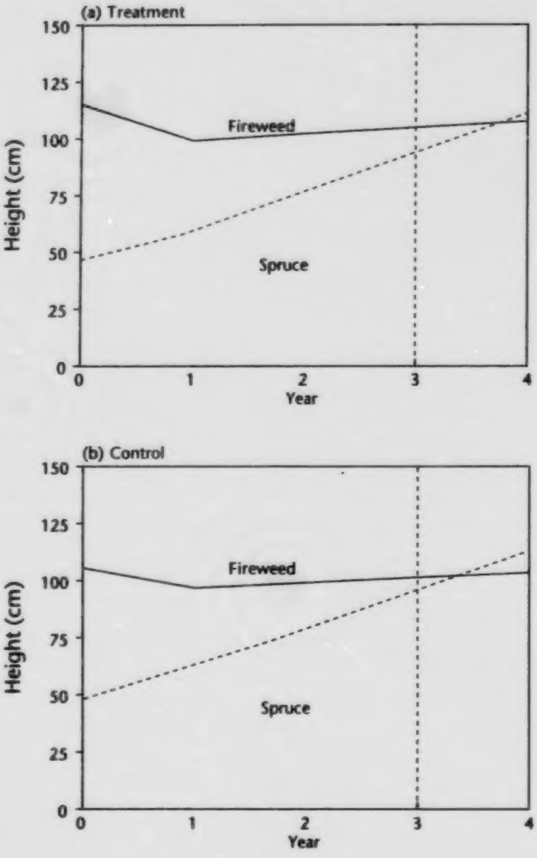


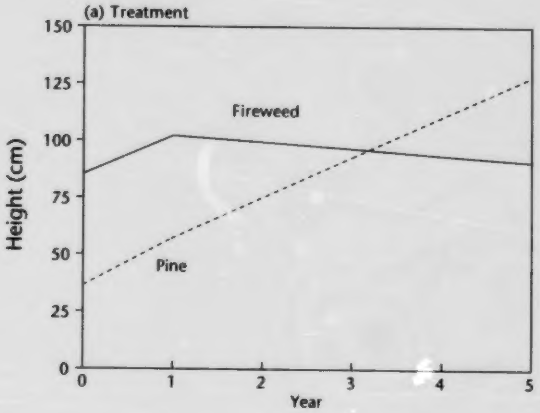
FIGURE 40 *Comparison of average spruce and fireweed height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ESSF/ICH* Fireweed Complex. *Heights for years 0 through 3 are based on actual data (the value for year 2 was interpolated), and the height for year 4 is projected on the basis of height growth rates in year 3. The vertical broken line indicates the most recent assessment year. Spruce are predicted to outgrow fireweed between years 3 and 4 after treatment in both the manual cutting treatment and the control.*

Brushing with glyphosate is predicted to decrease the time required for spruce to meet free-growing, but control seedlings are also predicted to meet the criteria well within the free-growing assessment window. Five years after brushing, spruce were 6–10 years old, and those in the glyphosate treatment (on average) fulfilled the minimum height requirement and were 144% as tall as the overall vegetation height, thereby suggesting that the criteria for free-growing were likely to be met within 1 year of the early free-growing assessment age. In comparison, control seedlings also met the minimum height requirement, but averaged only 83% as tall as the overall vegetation height. At the current rate of height growth, control seedlings are predicted to meet the conifer:vegetation height ratio requirement about 3 years later than treated seedlings (about 7 years after the glyphosate treatment was applied) (Figure 42). Control seedlings are therefore predicted to reach free-growing when they are 8–12 years old, which is well within the ICH free-growing window. The fifth-year silviculture survey indicated there were significantly more free-growing trees in the treatment (784 stems/ha) than the control (332 stems/ha), which supports our predictions.

Various studies in the southern interior suggest that both treated and untreated seedlings outgrow surrounding vegetation within the required time to meet free-growing, except in tall communities such as the *Mixed Broadleaf-Shrub* Complex (Simard and Heineman 1996a, 1996b, 1996c; Simard, Heineman, and Youwe 1998). In our study, we predict that neither manual nor chemical brushing will have been necessary for Engelmann spruce or lodgepole pine growing among the *Fireweed* Complex on circum-mesic sites to achieve free-growing, even where brushing resulted in improved seedling growth.

There is growing recognition that brushing treatments should be applied only when a quantifiable and lasting seedling response can be obtained; however, it is difficult to predict whether early significant differences in growth, even those that occur over a decade, are economically or ecologically cost-effective over the long term. Various studies suggest that conifer growth improves when abundance of the *Fireweed* Complex is reduced for at least 2–3 years. For instance, 5–10 years after glyphosate application, spruce seedlings had significantly greater stem diameter and were taller than control seedlings (Harper et al. 1997; Whitehead and Harper 1998; Comeau et al. 2000a), but the absolute differences in size were relatively small, and it is difficult to predict whether they will increase over time or gradually fade into insignificance. One long-term study found that early weed control continued to have a positive effect on white spruce growth for 3 decades, with height advantages of 10–50 cm at age 7 increasing to 70–100 cm by age 30, and stem diameter advantages of 0.4–1.0 cm increasing to 1.0–2.0 cm (Sutton 1995). However, even treatments that produce statistically significant growth improvements may still give trees only a 1- to 2-year advantage over those that were untreated (Burton et al. 2000).

(a) Treatment



(b) Control

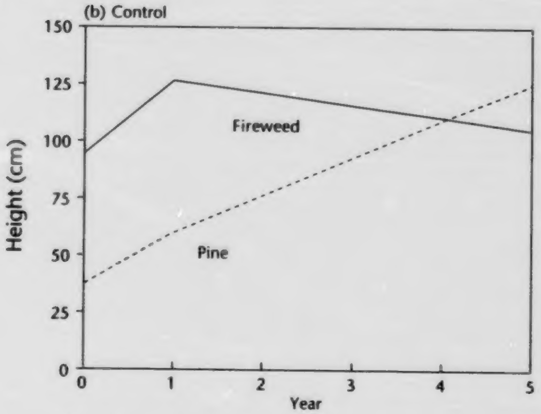


FIGURE 41 *Comparison of average lodgepole pine and fireweed height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH/ESSF* Fireweed *Complex. Values for years 2 and 4 were interpolated from actual data. Pine outgrew fireweed approximately 3 years after the manual cutting treatment and after 4 years in the control.*

In view of both the financial constraints currently affecting the forest industry and the necessity for protecting other resource values, silviculturists have more need than ever to focus brushing expenditures on sites where they can expect a measurable response in seedling survival and/or growth. Brushing the *Fireweed* Complex can be expensive, particularly where the use of herbicides is undesirable and two or three manual brushings are required to release seedlings (the average cost for three manual cutting passes is $1893 stems/ha in British Columbia (B.C. Ministry of Forests 1999)). PROBE results to date support the conclusions of Comeau et al. (2000a) that there is little benefit to applying a single manual cutting treatment; money is likely better spent treating fewer, more problematic sites with repeated treatments. Efforts should be made to more clearly characterize those sites where competition will be particularly severe, and where seedlings will exhibit the greatest response to brushing.

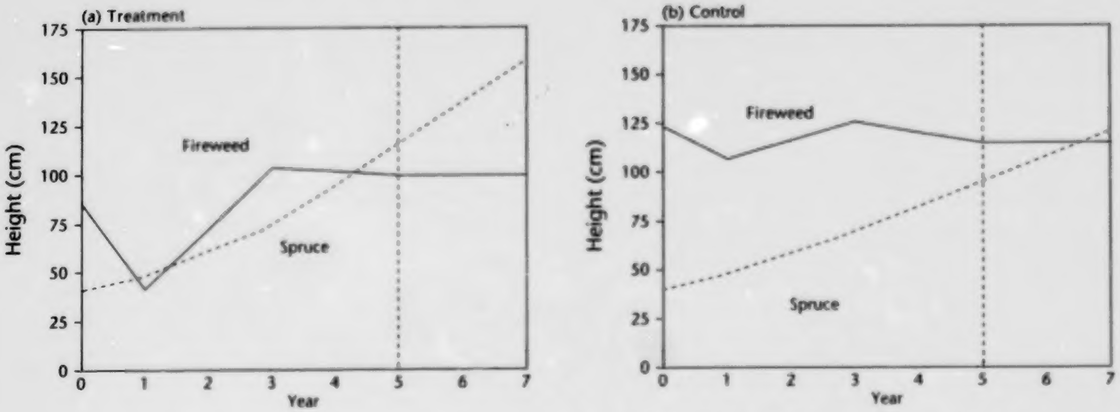


FIGURE 42 *Comparison of average spruce and fireweed height profiles in (a) the brushing treatment and (b) the control in the years following foliar glyphosate application in the ESSF/ICH* Fireweed Complex. *Heights for years 0 through 5 are based on actual data (values for years 2 and 4 were interpolated), and the height for years 6 and 7 are projected on the basis of height growth rates in year 5. The vertical broken line indicates the most recent assessment year. Spruce outgrew fireweed approximately 4 years after the glyphosate treatment and are predicted to do so after 7 years in the control.*

CONCLUSIONS

A single manual brushing treatment had very little effect on the *Fireweed* Complex on circum-mesic sites in the ESSF and ICH zones, and, as a result, did not improve either survival (which was good to excellent) or growth of conifer seedlings. In contrast to manual cutting, ground foliar glyphosate application on circum-mesic sites in the ESSF zone reduced fireweed and overall vegetation abundance for at least 5 years, resulting in improvements in seedling height:diameter ratio. Again, there was no effect on seedling survival, which was high in both the treatment and control. Competition thresholds identified in this study suggest that spruce tolerated slightly higher levels of fireweed competition in the ICH than in the ESSF zone. Similarly, spruce appeared to tolerate slightly higher fireweed competition than did lodgepole pine in the ICH zone. Regardless of these zone and species differences, the threshold results support the conclusion that conifer seedlings grow well under moderate levels of fireweed competition (35–45% cover) on circum-mesic sites.

Rather than applying single manual brushing treatments to sites with moderate development of the *Fireweed* Complex, money allocated for brushing may be better spent applying higher-efficacy treatments (e.g., repeated manual treatments, glyphosate, or repeated grazing treatments) to sites where competition is heavy and conifer performance is threatened. On sites where fireweed levels generally fall below the competition thresholds, most seedlings are predicted to achieve free-growing status (B.C. Ministry of Forests 2000) within the assessment window without brushing intervention.

1. Manual or chemical brushing of the *Fireweed* Complex on our mesic sites in the ESSF and ICH zones was not required for adequate survival of spruce or lodgepole pine seedlings. Further study is required to identify sites where competition from this community is so intense that it threatens seedling survival.
2. A single manual cutting treatment was of little value for releasing seedlings from competition in the *Fireweed* Complex. Other studies indicate that three repeat treatments, best applied in summer, are necessary for improvements in spruce growth.
3. A single glyphosate treatment (1.4–2.1 kg ai/ha) decreased seedling height:diameter ratio in our study, but neither treated nor control seedlings reached stressful levels.
4. It is predicted that spruce and pine seedlings will reach free-growing on circum-mesic sites in the ICH and ESSF zones within the free-growing assessment window (B.C. Ministry of Forests 2000), regardless of whether the *Fireweed* Complex is brushed or not.
5. Competition thresholds averaged 36, 46, and 40% cover, and 49, 60, and 49 CRH, for Engelmann spruce in the ESSF zone, Engelmann spruce in the ICH zone, and lodgepole pine in the ICH zone, respectively. These thresholds, as well as other competition and light studies, predict that adequate growth rates of spruce and pine can be maintained under moderate levels of fireweed.
6. Vascular plant diversity in the *Fireweed* Complex was not affected by manual, chemical, or grazing brushing treatments. In general, manual brushing had very little effect on the abundance of individual species, even fireweed. Brushing with glyphosate, on the other hand, reduced the cover of some species, including berry-producing shrubs that are important to wildlife, for 5 or more years.

SECTION 5

Fern Complex

ABSTRACT

We have fifth-year results demonstrating the effects of foliar glyphosate application (1.24–1.78 kg ai/ha) on hybrid spruce seedlings and the *Fern* Complex in the ICH zone. Chemical brushing substantially reduced abundance of the *Fern* Complex during the 5-year monitoring period and improved spruce seedling growth (but not survival) within 1–2 years. By year 5, spruce in the treatment had 59% greater stem diameter (4.14 versus 2.61 cm), were 25% taller (163.8 versus 130.6 cm), had 52% longer leaders (23 versus 15 cm), and had 20% lower height:diameter ratio (40.1 versus 50.1) than those in the control. Spruce were 2–4 years old at the time of brushing, and the glyphosate treatment was not necessary to ensure continued good (93%) survival. However, silviculture survey data collected at the start of the study suggest that considerable mortality occurred between the time of planting and brushing. In spite of its severe impact on vegetation, chemical treatment did not affect richness or diversity of the *Fern* Complex.

A competition threshold for spruce diameter growth was not evident where herb cover was used as a competition index, but was 58 where CRH was used. Reducing herb abundance below the CRH threshold for most trees over a 3-year period improved average spruce diameter growth. Other studies suggest that shorter-term reductions from single manual treatments are ineffective at releasing spruce seedlings from fern competition. The ability to identify CRH but not cover thresholds, as well as results from other studies, suggest that the *Fern* Complex affects spruce growth more by reducing light than by reducing soil resource availability.

In our study, brushing with glyphosate allowed treated spruce to achieve (on average) the minimum height and conifer:vegetation height ratio requirements for free-growing (B.C. Ministry of Forests 2000) by the time they were 7–9 years old. However, we predict that control seedlings will need only an additional 1–2 years to meet these requirements. Brushing did not improve the ability of our sites to meet minimum stocking because stocking was low at the time brushing treatments were applied.

Description of the *Fern* Complex

The *Fern* Complex is characterized by the presence of lady fern (*Athyrium filix-femina*), bracken (*Pteridium aquilinum*), and less abundantly, spiny wood fern (*Drypopteris expansa*) (Kimmins and Comeau 1990; Figure 43). The complex typically occurs as a mosaic of pure patches of lady fern, bracken fern, and thimbleberry (*Rubus parviflorus*), with each species occupying its own niche. Other herbs and shrubs that are often present in the *Fern* Complex include fireweed (*Epilobium angustifolium*), red raspberry (*Rubus idaeus*), devil's club (*Oplopanax horridus*), and red elderberry (*Sambucus racemosa*). The *Fern* Complex and *Mixed Shrub* Complex (Section 6) tend to include similar species, but ferns are less dominant in the *Mixed Shrub* Complex. The *Fern* Complex is found on moist to wet sites in wetter subzones of the ICH zone in the southern interior of British Columbia. It represents an important vegetation competition problem in the ICH zone.

Development of the *Fern* Complex

Bracken occurs in the understorey of mature forests, but the vigour and size of bracken colonies tend to increase following harvesting, especially when an intensive mechanical site preparation or deep burning treatment is applied subsequently (Haeussler et al. 1990). Severe disturbance provides a niche that bracken, but few other species, can tolerate. Bracken plants that were present before logging quickly invade vacant niches through vegetative reproduction from an extensive, rapidly reproducing network of underground rhizomes. The rhizomes are deep in the soil, and disturbance does not kill the plants but rather promotes the production of new fronds. The abundant wind-dispersed spores of bracken also quickly invade severely disturbed areas (Haeussler et al. 1990). Bracken does not compete well with other vegetation and so is usually not abundant on rich microsites where other species reproduce well, or where native vegetation is undisturbed (Hellum and Zahner 1966; Watt 1976; Fletcher and Kirkwood 1979). Once established, bracken can severely inhibit or exclude other plant species, including conifers (Ferguson and Boyd 1988), through production of toxic growth-inhibiting chemicals (allelopathy) (Gliessman 1976). Bracken's best growth is where moisture is abundant, but it can tolerate moderately dry conditions as well (Cody and Crompton 1975). It reaches heights of 1–1.5 m, or taller where conditions are favourable.

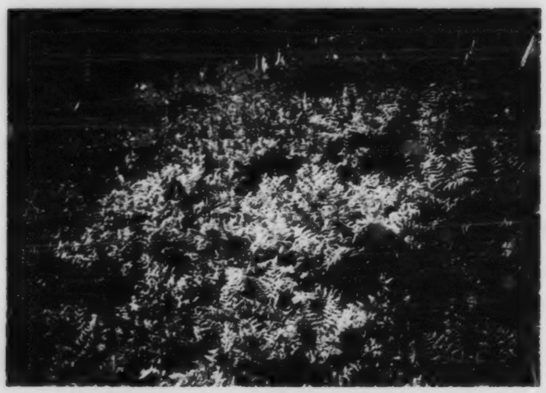


FIGURE 43 *The Fern Complex prior to glyphosate application at Ratchford River (Site 44) in the ICHwk1 variant in the Salmon Arm Forest District. Photo credit: Silver Ring Forestry Ltd.*

Lady fern usually becomes a dominant species on logged sites only if it was well established in the original stand (Haeussler et al. 1990). Growth and expansion of the plant are stimulated by the increase in light following canopy removal, but only where moisture is adequate. The presence of lady fern diminishes on sites that dry out after logging. Lady fern prefers moist to wet, well-drained medium to very rich soils (Page 1982; Pojar et al. 1982; Klinka et al. 1989). Plants that were present before logging reproduce through division of the rhizome, but unlike bracken fern, they do not form an extensive underground network of rhizomes (Haeussler et al. 1990). Lady fern also reproduces through spores, which will germinate on mineral soil or, less commonly, decaying wood. Spores do not usually germinate on the forest floor, and germination is reported not to occur under dry conditions or in the shade (Weinberg and Voeller 1969; Page 1979; Schneller 1979). Development of lady fern colonies is favoured by light to moderate burns, but tends to be retarded by mechanical site preparation (Haeussler et al. 1990). Lady fern can grow to heights of 1 m or more under suitable conditions.

Thimbleberry patches are common in the *Fern* Complex. Canopy removal, burning, and mechanical site preparation (MSP) all stimulate sprouting from rhizomes of thimbleberry plants that were present before logging, and burning and MSP create suitable conditions for germination of new or banked seed (Haeussler et al. 1990). Once established, thimbleberry plants quickly expand into colonies through vegetative reproduction of the rhizomes. Thimbleberry tends to rapidly increase in cover and height, and often develops a dense canopy with a very large leaf area within a few years of disturbance. Thimbleberry will grow under a wide variety of nutrient conditions, but growth is best where soils are moist and well-drained (Haeussler et al. 1990). Under suitable conditions, thimbleberry can achieve a height of 2 m.

In summary, the *Fern* Complex most commonly develops on moist ICH sites that were burned and where lady fern and bracken were present before logging. Because moist sites are difficult to burn, it is less widespread than other plant communities such as the *Mixed Shrub* Complex. Bracken generally becomes a significant component of the plant community only on microsites where disturbance was severe, and lady fern tends to develop only where nutrients are medium to rich. Thimbleberry establishes under a wider range of conditions than the ferns.

Interactions with Conifer Seedlings

The dominant species of the *Fern* Complex (lady fern, bracken, and thimbleberry) are all serious competitors for light (Haeussler et al. 1990), and they can cause physical damage to young conifers by smothering them with dense foliage in the fall. Burton (1996) likewise cites bracken fern patches as one of the most inhibitive environments for conifer seedling growth. Seedlings likely experience minimal competition for moisture and nutrients from the *Fern* Complex because it tends to occur on moist to wet sites with at least medium nutrient levels. It is possible, however, that excess moisture and high humidity under extremely dense vegetation of this nature can cause seedlings to rot. The *Fern* Complex is known to reduce spruce growth (Comeau et al. 1993), but there are no published reports of negative effects on survival. Nevertheless, high seedling mortality has commonly been observed immediately following planting in fern-dominated openings, which has sometimes led to stocking problems (J. Wright, pers. comm., 2000).

Importance to Wildlife and Range

The *Fern* Complex is utilized by ungulates, bears, and small mammals. Bracken fern is an important food source for deer (Harvey 1981) and it can provide part of the late fall or winter diet of caribou (Edwards and Ritcey 1960). Lady fern is an important food for mountain goat and a moderately important food for bighorn sheep, but has low importance in the southern interior for deer, moose, and caribou (Blower 1982). Its fiddleheads and mature fronds are eaten by black bear, grizzly bear, and deer in spring and summer (Haeussler et al. 1990). Thimbleberry fruit is favoured by many birds and mammals, but the twigs and leaves have fairly limited value as a food source (Haeussler et al. 1990). The dense patches of vegetation that commonly occur in *Fern* complexes provide cover for many mammals.

Thimbleberry and bracken are browsed minimally or erratically by sheep; bracken tends to be trampled more than browsed (Newsome et al. 1995). The value of lady fern as sheep browse has not been documented in the literature.

Common Brushing Treatments in the *Fern* Complex

Manual cutting and foliar glyphosate application are the only common operational brushing treatments used on the *Fern* Complex. Details about these treatments are found in Table 37. Manual cutting is used more frequently than herbicides, sometimes due to difficulties of obtaining herbicide permits. Manual cutting treatments may be single or repeated, but glyphosate is generally applied only once. Manual cutting and herbicide treatments may be applied as either broadcast or spot applications. In this study, the only treatment assessed was glyphosate application.

TABLE 37 *Common brushing treatments applied to the Fern Complex in the southern interior of British Columbia*

Treatment	Objective	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantage
Manual cutting	1. Reduce competition for light 2. Reduce snow- and vegetation-press	Spring or spring and and mid-summer[b]	Multiple	1. Motorized brush saw 2. "Hockey stick"	$538 $511	1. Treatment damage to seedlings 2. Multiple treatments are expensive
Glyphosate (1.24–1.78 kg ai per ha)	1. Reduce competition for light 2. Reduce snow- and vegetation-press	Mid-July to late August[c]	1	1. Backpack sprayer 2. Fixed-wing plane or helicopter (aerial)	$700 $311	1. Difficulties obtaining herbicide permits 2. Cannot apply near waterways

[a] Based on average costs for the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)
[b] Comeau et al. (2000)
[c] LePage and Pollack (1988)

Foliar Glyphosate

Engelmann spruce in the ICH zone

This section describes fifth-year hybrid spruce and vegetation responses to a single foliar glyphosate treatment of the *Fern* Complex (n = 3). Seedlings were 2–4 years old at the time of treatment.

Description of study sites and treatments

The response of spruce and the *Fern* Complex to glyphosate application is being studied on three sites in the Kamloops and Nelson forest regions. Two of the sites are located near the Ratchford River, 50 km northwest of Malakwa in the Salmon Arm Forest District, and the third site is located near Bigmouth Creek, south of the Mica Dam in the Revelstoke District. All of the sites are located northwest of Revelstoke in wet ICH variants (Wells Gray Wet Cool ICH variant [ICHwk1] and Mica Very Wet Cool ICH variant [ICHvk1]). The two Ratchford River sites, which are very similar, share a common control plot because of accidental destruction of one of the original control plots. Consequently, analysis for this treatment cell used an unbalanced design.

The sites are all mesic (site series 01) with moderately steep slopes (40–50%), but aspect is variable (Table 38). Two sites are transitional to the ESSF zone (1350–1400 m), whereas the third is in the heart of the ICH zone at 800 m elevation. The higher-elevation sites have sandy loam Podzolic soils, whereas the lower-elevation site has a sandy clay loam Brunisolic soil.

The original stands were clearcut in 1987–1991. Two sites were burned immediately after logging and the third was not site-prepared. Spruce were planted on each site within 1 year of disturbance. Herbicide was applied when the seedlings were 2–4 years old (50–70 cm tall), which was 3–6 years after logging. The spruce were one-half to two-thirds the height of the neighbouring vegetation and most trees were overtopped at the time of brushing. Most seedlings were of moderate vigour; only about 5% were in poor condition. Total conifer stocking at the time of brushing ranged from 978 to 1575 stems/ha (Table 38). Two sites were adequately stocked (836–858 well-spaced stems/ha), but the third had only 200 well-spaced conifers/ha when it was brushed.

Vegetation was lush at the time of glyphosate application. The plant community was about 1 m tall on each site and total vegetation cover was 70–94%. Lady fern cover was 17–38%, bracken cover 0–10%, thimbleberry cover 8–19%, and fireweed 8–18%.

The sites were treated with glyphosate in the latter part of August under favourable weather conditions (Table 39). The sites near Ratchford River received broadcast herbicide applications at 1.6–1.78 kg ai/ha and the Bigmouth Creek site was treated with spot applications at a rate of 1.24 kg ai/ha.

Conifer response

Survival and vigour Five years after the application of foliar glyphosate to the *Fern* Complex, survival of 7- to 9-year-old hybrid spruce seedlings (2–4 years old at the time of treatment) averaged 93% in the chemical treatment and the control ($p = 0.27$) (Table 40). The main cause of mortality was vegetation competition. According to the fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), there were 589 and 286 free-growing stems/ha in the treatment and control, respectively ($p = 0.08$). The survey was conducted before the early assessment date on some sites.

Spruce vigour improved modestly during the 5-year assessment period, and more so in the treatment than the control (Figure 44). By year 5, approximately two-thirds of treated trees were of good vigour, and only 2% were poor. In comparison, 50% of the control seedlings were of good vigour in year 5 and 12% were poor.

Vegetation competition was the major reason that vigour of spruce seedlings declined in both the brushing treatment and control. The most common defects resulting from competing vegetation were bent stems and forks, and a small percentage of seedlings had thin or stunted foliage. Seedlings in the treatment generally outgrew bent stems within 3 years of brushing, whereas control seedlings had only partially overcome this problem after 5 years. The incidence of thin and stunted foliage became less common over time in both the treatment and control.

TABLE 38 *Characteristics and history of the three replicate study sites where the ICH Fern Complex was treated with glyphosate in hybrid spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (years)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Ratchford River PROBE 44 Salmon Arm District	ICHwk1 01 (mesic)	1350	S 50%	Podzol/ sandy loam	Clearcut 1988 Burned 1988	6	6	1	P 1989–1990	PSB 313	4	65 (17)	Lady fern cover: 38 (26) Lady fern height: 94 (24) Bracken cover: 10 (16) Bracken height: 50 (52) Fireweed cover: 18 (19) Fireweed height: 113 (52) Thimbleberry cover: 11 (15) Thimbleberry height: 59 (38) All veg. cover: 94 (8) All veg. height: 110 (28)	1375	836
Ratchford River PROBE 45 Salmon Arm District	ICHwk1 01 (mesic)	1400	SW 40%	Podzol/ sandy loam	Clearcut 1991	3	n/a	0	P 1991	PSB 415 2+0	2	64 (14)	Lady fern cover: 29 (26) Lady fern height: 79 (33) Bracken cover: 7 (11) Bracken height: 50 (47) Thimbleberry cover: 19 (20) Thimbleberry height: 64 (36) Fireweed cover: 8 (11) Fireweed height: 79 (56) All veg. cover: 93 (8) All veg. height: 96 (21)	1575	858

TABLE 38 *Continued*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (years)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Bigmouth Creek PROBE 102 Revelstoke District	ICHvk1 01 (mesic)	800	NW 45%	Brunisol/ sandy clay loam	Clearcut 1987–1989 Burned 1990	3	2	0	P 1990	Unknown	2	51 (10)	Lady fern cover: 17 (18) Lady fern height: 64 (33) Thimbleberry cover: 8 (12) Thimbleberry height: 36 (35) Fireweed cover: 16 (16) Fireweed height: 103 (36) Devil's club cover: 11 (13) Devil's club height: 37 (23) All veg. cover: 70 (19) All veg. height: 91 (32)	978	200

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting

[b] Origin: P = planted; N = natural regeneration

[c] Age refers to the number of years since planting

[d] Values are means and one standard deviation (in parentheses)

TABLE 39 *A description of glyphosate treatments applied to the three replicate study sites to release hybrid spruce seedlings growing in the ICH Fern Complex*

Site	Initial treatment date	Application method	Application tool	Application rate (kg ai per ha)	Weather at treatment	Precipitation after treatment
Ratchford River	August 27, 1994	Broadcast aerial spray	Helicopter	1.6	Dry foliage 13–15°C 75–80% RH 1 km per hr wind	None
Ratchford River	August 27, 1994	Broadcast aerial spray	Helicopter	1.78	Dry foliage 13–15°C 75–80% RH 1 km per hr wind	None
Bigmouth Creek	August 20, 1992	Broadcast ground foliar spray	Backpack sprayer	1.24	Unknown	None

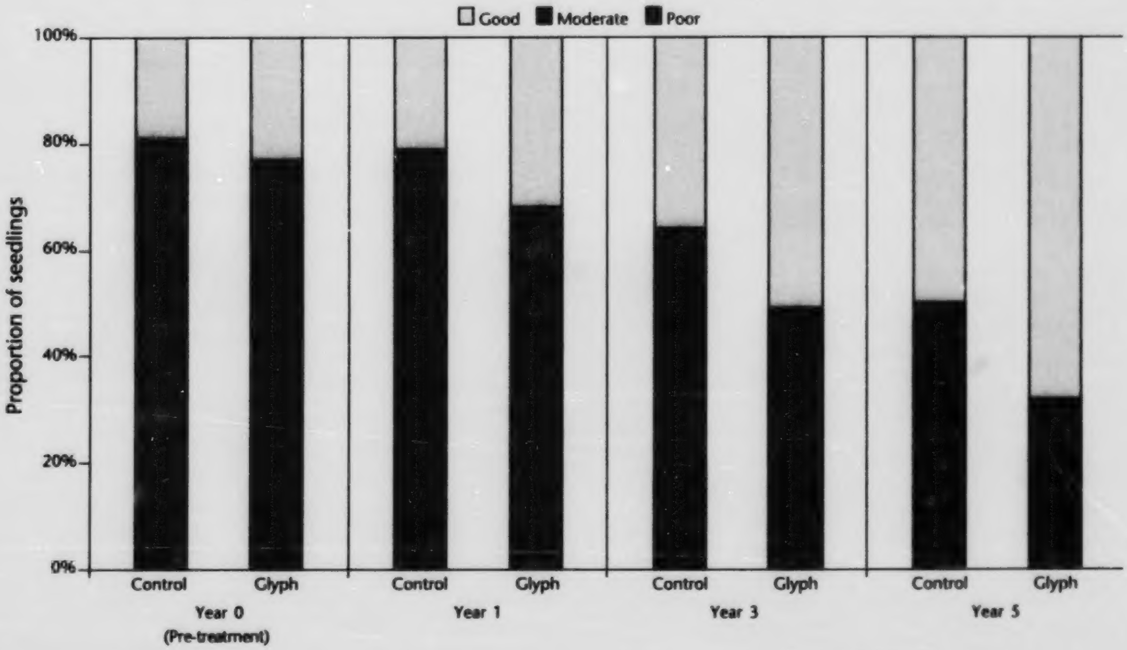


FIGURE 44 *Comparison of hybrid spruce vigour between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Fern Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

TABLE 40 *Survival and growth responses of hybrid spruce seedlings to glyphosate treatment in the ICH Fern Complex*

Response variable	Means Glyphosate	 Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	100	100	0.000	1.00
3 yr post-treatment	99	96	1.135	0.23
5 yr post-treatment	97	89	3.928	0.27
Stem diameter (cm)				
Pre-treatment	1.08	0.92	0.050	0.15
1 yr post-treatment	1.61	1.18	0.109	0.11
3 yr post-treatment	2.83	1.76	0.210	0.07*
5 yr post-treatment	4.14	2.61	0.296	0.07*
Diameter increment (cm)				
1 yr post-treatment	0.53	0.26	0.059	0.08*
3 yr post-treatment	0.63	0.31	0.067	0.08*
5 yr post-treatment	0.64	0.43	0.042	0.07*
Height (cm)				
Pre-treatment	63.8	56.0	1.685	0.08*
1 yr post-treatment	77.4	67.1	1.809	0.30
3 yr post-treatment	116.1	94.9	1.830	0.01*
5 yr post-treatment	163.8	130.6	4.793	0.04*
Leader length (cm)				
Pre-treatment	13.6	11.1	0.753	0.15
1 yr post-treatment	13.8	11.9	0.553	0.13
3 yr post-treatment	21.1	13.6	1.310	0.06*
5 yr post-treatment	23.1	15.2	1.948	0.10*
Height:diameter ratio				
Pre-treatment	60.3	61.5	1.055	0.51
1 yr post-treatment	49.7	57.7	1.520	0.07*
3 yr post-treatment	42.1	54.2	1.824	0.04*
5 yr post-treatment	40.1	50.1	1.609	0.05*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

Although survival and vigour were good after brushing, silviculture survey information collected at the start of the study suggests that some mortality and a decline in seedling condition occurred in the 2–4 years between planting and brushing. In particular, when the Bigmouth Creek site was brushed, there were a total of 978 conifer stems/ha, but only 200 stems/ha were well spaced. Total conifer stocking is likely below the density that was planted, and the very low number of well-spaced trees suggests that many trees were of unacceptable condition at the time of brushing. The two sites near Ratchford River had total conifer stocking of 1375–1575 stems/ha (836–858 stems/ha well-spaced) when brushing occurred, suggesting that little mortality had occurred between planting and brushing.

Growth Growth of hybrid spruce seedlings improved within 1–3 years of glyphosate application (Table 40). Height:diameter ratio was significantly lower in the treatment (49.7) than the control (57.7) within 1 year of treatment (p = 0.07), and continued to be lower through year 5 (40.1 versus 50.1, p = 0.05). Within 3 years of the chemical treatment, stem diameter, diameter increment, height, and leader length had improved significantly in the treatment relative to the control and these improvements continued through year 5 ($p<0.10$). Analysis of covariance was applied to height data to address pre-treatment differences between the treatment and control that had been determined by ANOVA. After 5 years, treated seedlings had 59% (1.53 cm) larger stem diameters (Figure 45) and

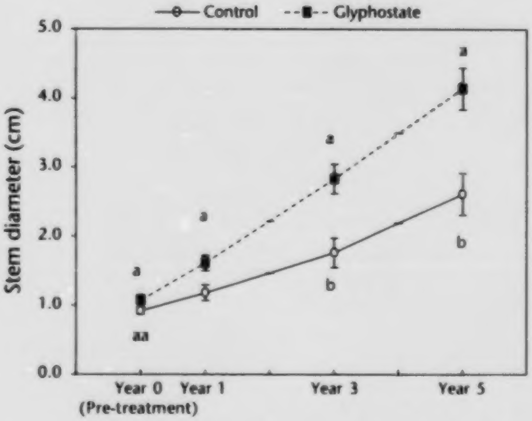


FIGURE 45 *Comparison of hybrid spruce stem diameter between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Fern Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

were 25% (33.2 cm) taller (Figure 46) than those in the control. At that time, average leader length was 23.1 cm in the treatment compared to 15.2 cm in the control ($p = 0.10$).

Standardized stem diameter distributions for spruce (Figure 47) are consistent with ANOVA results showing that diameter growth increased in response to glyphosate treatment. The distributions show a pronounced trend of increasing stem diameter in the treatment relative to the control. By year 5, the majority of control seedlings were in diameter classes that were -0.5 to -2 below the mean, whereas most treated seedlings were in diameter classes that were up to +2 above the mean. Height distributions (Figure 48) were approximately normal, and were similar in the treatment and control. They changed little from the pre-treatment assessment to year 5, which is consistent with the small spruce height response shown by ANOVA.

Competitive status Brushing with glyphosate greatly reduced abundance of the *Fern* Complex and decreased the extent of seedling overtopping. The percentage of overtopped seedlings was reduced from 79% before treatment to 12% 1 year afterward and the percentage of seedlings that were free of vegetation increased from 0 to 54% (Figure 49). Vegetation partially recovered within 3 years, resulting in about three-quarters of treated seedlings again being threatened or overtopped. However, seedlings were gaining on the vegetation canopy, and, by year 5, 44% of those in the treatment were free of vegetation, 47% were threatened, and only 9% were overtopped. In comparison at that time, 14% of control seedlings were free of vegetation, 51% were threatened, and 35% were overtopped.

Plant community responses

Abundance Vegetation abundance was greatly reduced 1 year after glyphosate application, and after 5 years the effects of treatment were still somewhat apparent (Table 41, Figure 50). Total vegetation cover was reduced from 87.5 to 51.7% in the first-year assessment ($p = 0.03$) (Figure 51), and, likewise, cover of herbs, shrubs, lady fern, and thimbleberry were also reduced ($p<0.10$). Height of lady fern, shrubs, and thimbleberry was reduced in the treatment compared to the control in year 1 ($p<0.10$), but differences in total vegetation and herb height were not significant due to the wide variability among sites ($p>0.10$). In year 3, height of most vegetation components was significantly less in the treatment than the control.

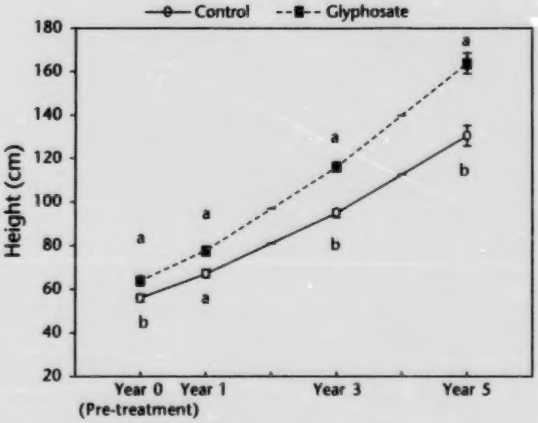


FIGURE 46 *Comparison of hybrid spruce height between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Fern Complex. Error bars are one standard error. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10). Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.*

Five years after treatment, lady fern cover and height were 4.7% and 36.7 cm, respectively, compared to 36.7% and 79.5 cm in the control. Overall vegetation cover and height also continued to be significantly lower in the treatment than the control, as were herb cover, shrub height, and thimbleberry height. Fireweed was not particularly abundant at the start of the assessment period (average 14% cover) and it was not affected by treatment. By year 5, its cover had increased to an average of 26.9% in the treatment and control.

Richness and diversity of individual species and structural vegetation groups Brushing the *Fern* Complex with glyphosate had no effect on either species richness or diversity ($p>0.10$) (Table 42). Species richness remained constant (35 species) between the pre-treatment and fifth-year assessments (no data were available for year 3). Neither

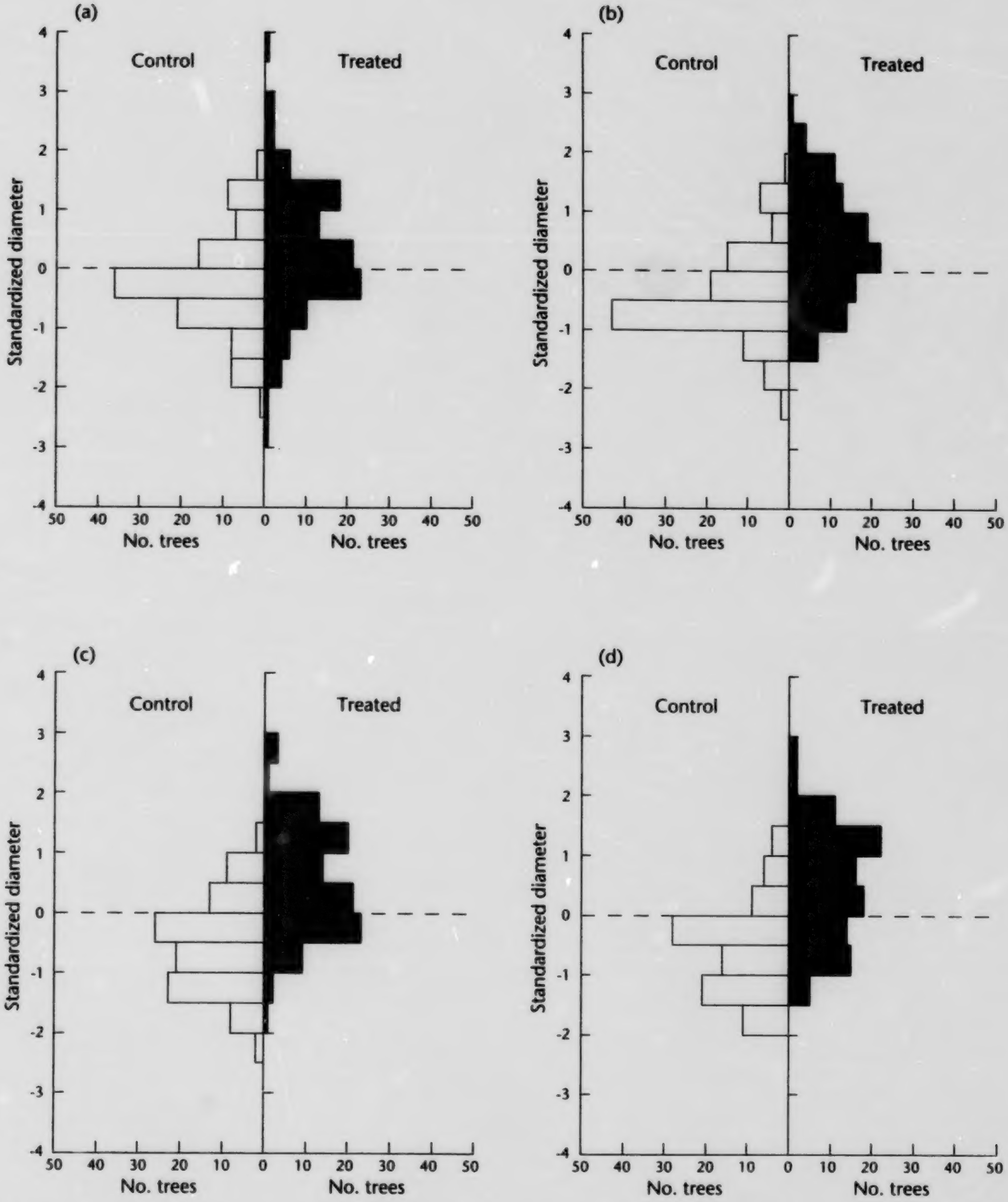


FIGURE 47 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH* Fern *Complex before and after glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

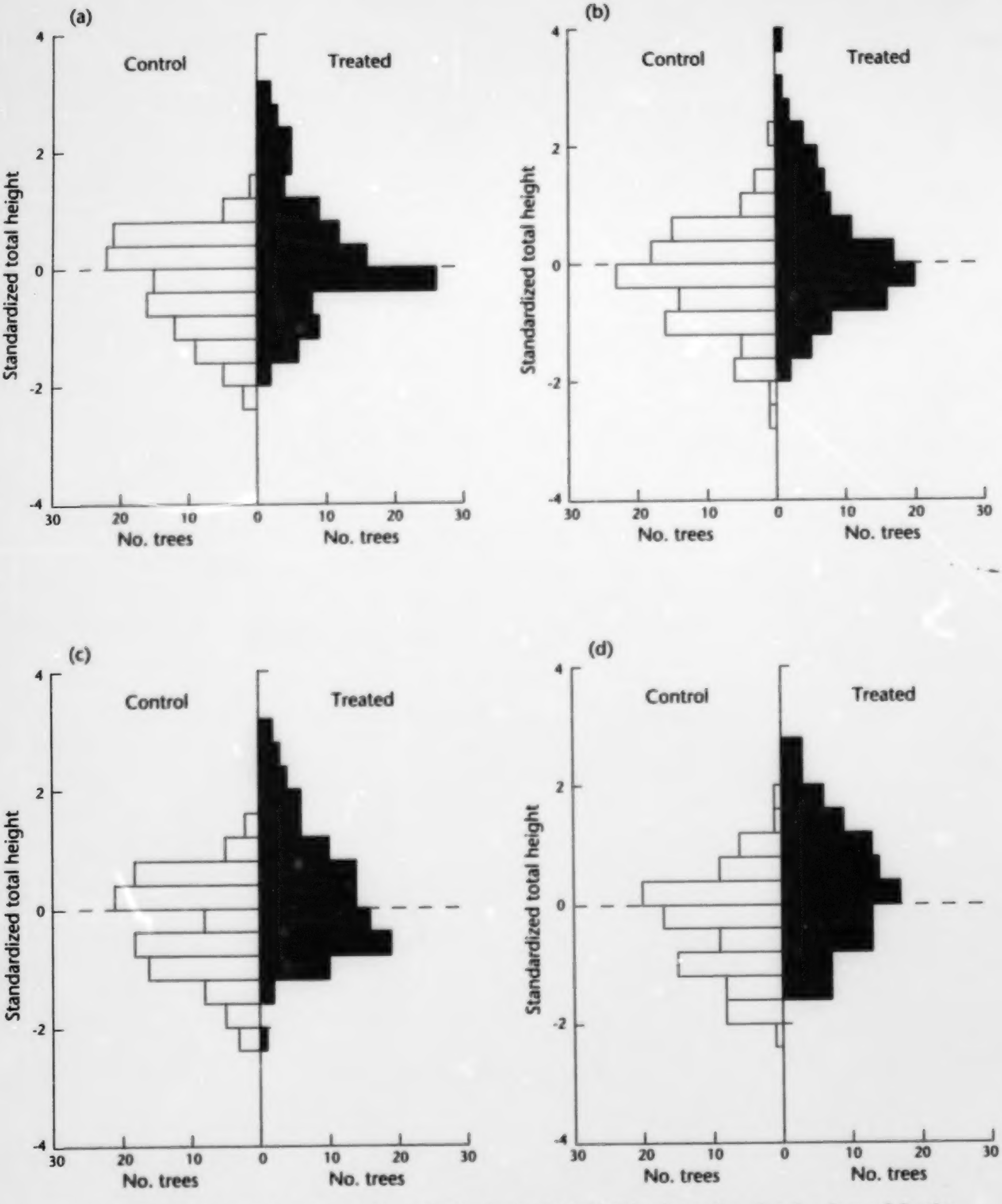


FIGURE 48 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH* Fern Complex *before and after glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

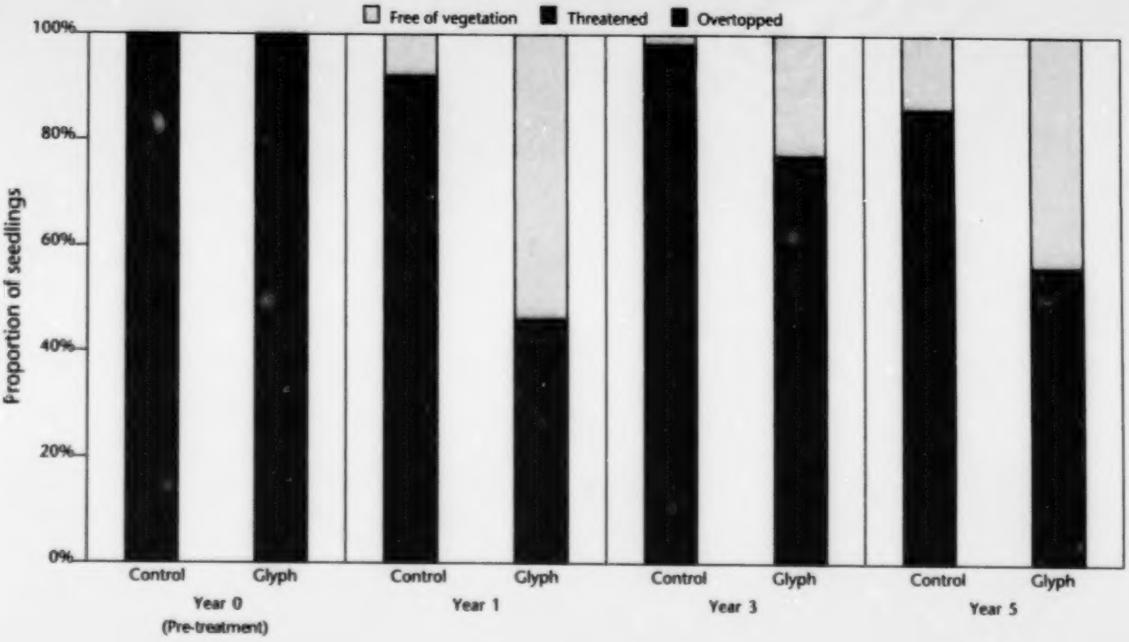


FIGURE 49 *Comparison of hybrid spruce competitive status between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Fern Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

were there differences in the number or diversity of structural vegetation groups (p>0.10) (Table 43).

Although richness and diversity were not affected by the treatment, there were some changes in the abundance of individual species (Table 44). Glyphosate treatment of the *Fern* Complex reduced the cover of many low shrub (<2 m) and herb species 1 year after brushing. Thimbleberry was abundant (approximately 20% cover) on all three sites at the time of brushing treatment and its cover was reduced to around 5% by the herbicide treatment. Devil's club (*Oplopanax horridus*) and black huckleberry (*Vaccinium membranaceum*) were also common (7–8% cover) on two of the sites, and their cover was reduced to 1–2% in treated plots.

The *Fern* Complex is characterized by a lush herb and low shrub layer, and the objective of the herbicide treatment is to reduce its abundance. This applies particularly to tall herbs that restrict the amount of light reaching seedlings. Glyphosate reduced the abundance of lady fern on all three sites and virtually eliminated bracken and spiny wood fern on two of three sites. Abundance of three low herbs, oak fern (*Gymnocarpium dryopteris*), Queen's cup (*Clintonia uniflora*), and foamflower (*Tiarella* spp.), was also considerably reduced on two of three sites (not necessarily the same two). Two small herbs increased in abundance on at least two sites following treatment, although it is possible that they just increased in visibility following removal of taller species; purple-leaved willowherb (*Epilobium ciliatum*) appeared in minor amounts and violet (*Viola* spp.) increased in abundance.

Competition thresholds

Competition thresholds were derived using the three chemically treated plantations in the *Fern* Complex, plus site 19. The thresholds were based on cover and height of all herb species in the complex, where CRH = (herb cover * modal herb height)/spruce height.

TABLE 41 *Cover and height of vegetation in the ICH Fern Complex before and after glyphosate treatment in hybrid spruce plantations*

Response variable	Means		Standard error	p-value
	Glyphosate	Control		
All vegetation				
Cover (%)				
Pre-treatment	82.5	88.6	3.387	0.33
1 yr post-treatment	51.7	87.5	4.795	0.03*
3 yr post-treatment	78.9	90.5	3.565	0.15
5 yr post-treatment	76.3	87.5	1.624	0.04*
Height (cm)				
Pre-treatment	96.0	102.3	10.069	0.70
1 yr post-treatment	41.3	92.8	13.792	0.12
3 yr post-treatment	84.2	99.6	3.200	0.08*
5 yr post-treatment	78.7	103.6	6.024	0.08*
Herbs				
Cover (%)				
Pre-treatment	56.0	72.4	4.667	0.13
1 yr post-treatment	42.9	67.1	4.996	0.08*
3 yr post-treatment	64.7	70.3	1.785	0.16
5 yr post-treatment	66.2	74.1	0.872	0.02*
Height (cm)				
Pre-treatment	93.0	87.5	6.121	0.59
1 yr post-treatment	39.7	87.0	17.813	0.20
3 yr post-treatment	80.1	94.7	3.390	0.09*
5 yr post-treatment	76.8	98.3	6.818	0.13
Shrubs				
Cover (%)				
Pre-treatment	34.4	25.8	7.857	0.52
1 yr post-treatment	11.9	26.2	2.479	0.06*
3 yr post-treatment	22.5	33.3	4.777	0.25
5 yr post-treatment	19.2	25.2	3.344	0.33
Height (cm)				
Pre-treatment	85.0	103.1	16.635	0.52
1 yr post-treatment	32.7	82.6	8.967	0.06*
3 yr post-treatment	67.8	93.3	4.310	0.05*
5 yr post-treatment	64.1	95.9	7.759	0.10*
Lady fern				
Cover (%)				
Pre-treatment	17.1	39.1	5.047	0.09*
1 yr post-treatment	2.1	34.5	6.938	0.08*
3 yr post-treatment	4.8	32.7	7.194	0.11
5 yr post-treatment	4.7	36.7	7.423	0.10*
Height (cm)				
Pre-treatment	71.9	85.7	6.338	0.27
1 yr post-treatment	27.1	90.0	12.683	0.07*
3 yr post-treatment	46.0	89.5	10.716	0.10*
5 yr post-treatment	36.7	79.5	9.146	0.08*
Fireweed				
Cover (%)				
Pre-treatment	18.7	9.2	4.213	0.25
1 yr post-treatment	11.7	12.8	2.269	0.76
3 yr post-treatment	23.8	23.1	2.575	0.85
5 yr post-treatment	27.7	26.1	2.485	0.70
Height (cm)				
Pre-treatment	113.0	83.7	14.042	0.28
1 yr post-treatment	53.7	81.8	8.963	0.16
3 yr post-treatment	96.9	108.0	4.669	0.23
5 yr post-treatment	98.5	113.1	5.134	0.23
Thimbleberry				
Cover (%)				
Pre-treatment	18.8	7.9	6.598	0.37
1 yr post-treatment	2.7	9.7	1.137	0.05*
3 yr post-treatment	5.9	13.5	1.405	0.06*
5 yr post-treatment	6.1	10.7	1.817	0.22
Height (cm)				
Pre-treatment	61.8	51.3	8.290	0.47
1 yr post-treatment	19.1	46.9	4.305	0.04*
3 yr post-treatment	36.8	66.2	4.846	0.05*
5 yr post-treatment	31.1	56.5	6.093	0.10*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean $(\bar{y})$ was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

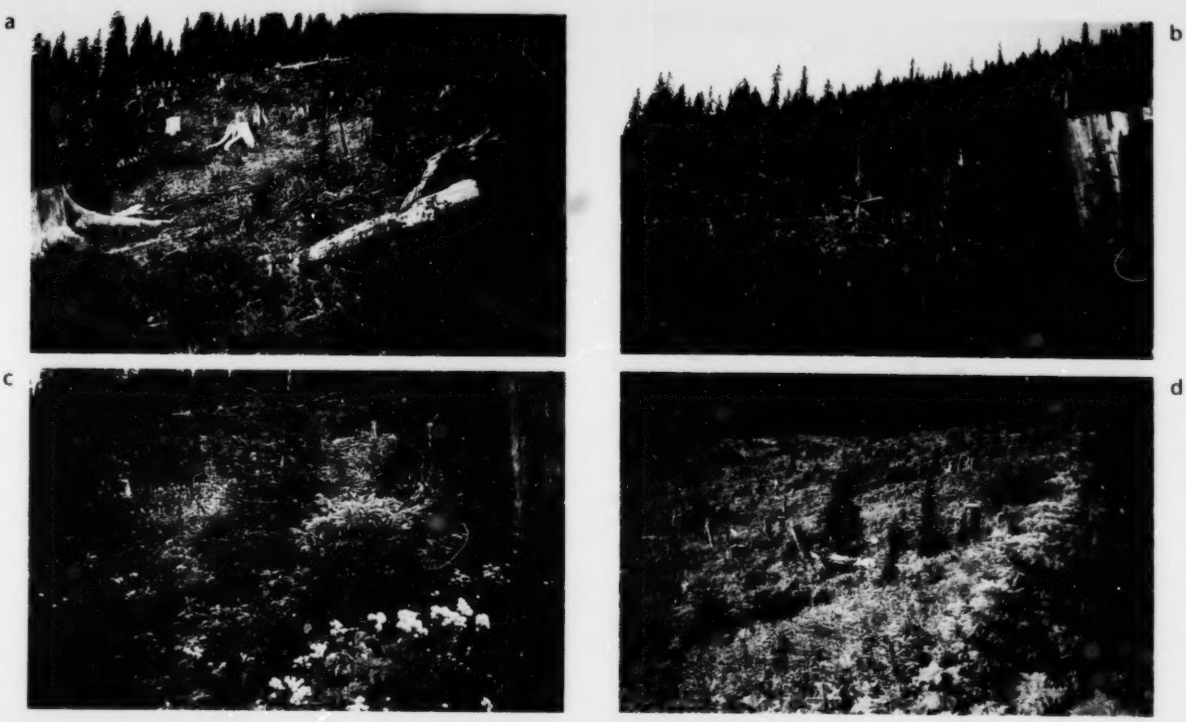


FIGURE 50 *Effects of broadcast foliar glyphosate application on the Fern Complex and Engelmann spruce (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Vegetation abundance was reduced by glyphosate for 5 years. Photo credit: Silver Ring Forestry Ltd.*

TABLE 42 *Richness and diversity of vascular plant species in the ICH Fern Complex before and after glyphosate treatment in hybrid spruce plantations*

Response variable	Means Glyphosate	 Control	Standard error	p-value
Richness				
Pre-treatment	35.33	35.67	3.704	0.96
1 yr post-treatment	36.67	34.33	2.014	0.50
5 yr post-treatment	36.33	33.33	3.240	0.58
Shannon-Weaver Diversity Index				
Pre-treatment	2.46	2.49	0.151	0.87
1-yr post-treatment	2.47	2.31	0.097	0.35
5-yr post-treatment	2.50	2.35	0.188	0.62
Simpson's Diversity Index				
Pre-treatment	0.86	0.87	0.022	0.63
1-yr post-treatment	0.85	0.84	0.014	0.62
5-yr post-treatment	0.86	0.85	0.028	0.76

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 43 *Richness and diversity of structural vegetation groups in the ICH Fern Complex before and after glyphosate treatment in hybrid spruce plantations*

Response variable	Means Glyphosate	 Control	Standard error	p-value
Richness				
Pre-treatment	5.67	5.67	0.408	1.00
1 yr post-treatment	5.67	5.00	0.236	0.18
5 yr post-treatment	6.00	6.00	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.14	1.24	0.079	0.45
1 yr post-treatment	1.18	1.08	0.066	0.37
5 yr post-treatment	1.16	1.26	0.064	0.38
Simpson's Diversity Index				
Pre-treatment	0.63	0.67	0.032	0.42
1 yr post-treatment	0.63	0.60	0.016	0.37
5 yr post-treatment	0.61	0.65	0.033	0.44

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

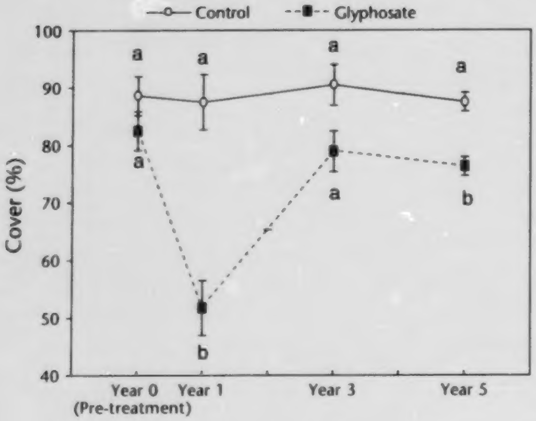


FIGURE 51 *Comparison of mean total vegetation cover between the glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Fern Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

A threshold for hybrid spruce diameter growth was not evident using herb cover as the competition index on any of the sites studied. Additionally, none of the linear regressions between spruce diameter and herb cover was significant ($p>0.10$) (Table 45). This is because spruce diameter varied similarly across all herb cover classes (e.g., Figure 52).

In contrast, spruce diameter declined sharply above the CRH threshold, which averaged 58 (e.g., Figure 52). There was little variation in thresholds among sites, which may be associated with the narrow range in age of planted seedlings (2–4 years old). Half the trees were growing in neighbourhoods above the thresholds, and may therefore benefit from further selective brushing. Most trees above the thresholds were control trees (67%), whereas most below the thresholds were treated trees (69%). Most treated trees (74%) fell below the thresholds, indicating that brushing was moderately successful at reducing herb abundance below the competition thresholds. The glyphosate treatments improved both mean diameter growth ($p<0.10$) (Table 40) and the distribution of spruce diameters across herb neighbourhoods (e.g., Figure 52), indicating that long-term reductions in herb abundance resulting from glyphosate application improved growing conditions for hybrid spruce.

TABLE 44 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following glyphosate treatment of the ICH Fern Complex in hybrid spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Low shrubs		*Oplopanax horridus* *Rubus parviflorus* *Vaccinium membranaceum*	*Ribes lacustre*
Herbs	*Epilobium ciliatum* *Viola glabella*	*Athyrium filix-femina* *Clintonia uniflora* *Dryopteris expansa* *Epilobium angustifolium* *Gymnocarpium dryopteris* *Pteridium aquilinum* *Tiarella* spp.	*Smilacina racemosa*

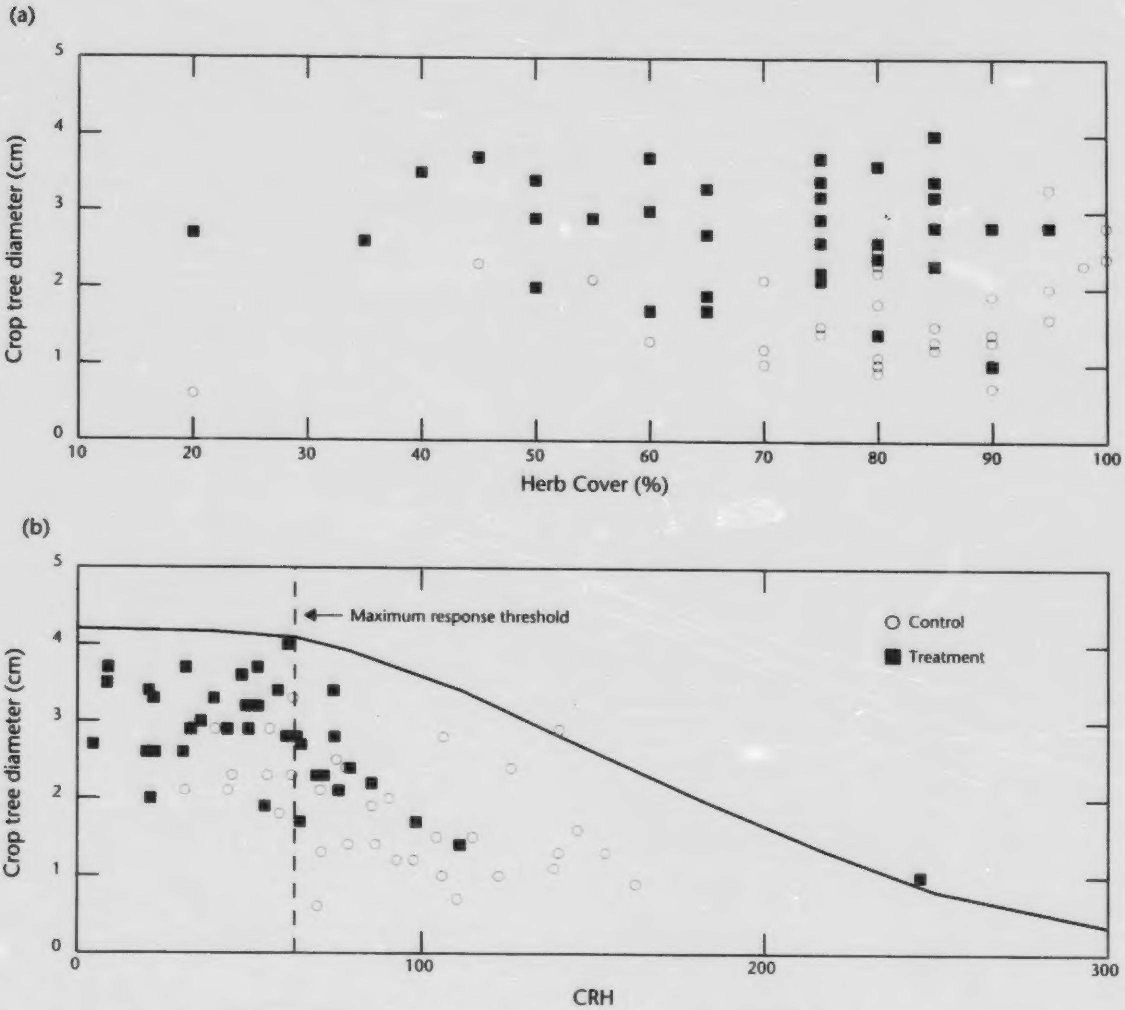


FIGURE 52 *Relationship between stem diameter of hybrid spruce growing amongst the ICH Fern Complex and (a) herb cover or (b) CRH, where CRH = (herb cover * herb modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 45 (n = 70). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

Linear regressions of spruce diameter versus fern CRH were significant for all four sites ($p<0.10$) (Table 45). Coefficients of determination were moderately high (adjusted r^2 0.05–0.40) and the slopes were relatively steep (β_1 -0.013 to -0.022) compared with other complexes. Fitting a negative exponential function to the diameter-CRH relationship did not improve the adjusted r^2 values. The adjusted r^2 values and slopes of these relationships indicate that competition as measured by fern CRH was moderately important and intense in the plantations.

TABLE 45 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting hybrid spruce stem diameter from the competition indices, herb cover and CRH, in the Fern Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from fern cover[a]	Adjusted r^2 for linear regression predicting diameter from fern cover[a]	p-value for linear regression predicting diameter from fern cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
19	19	1	None	$y = 2.185 + 0.006\,x$	0.00	0.71	60	$y = 3.300 - 0.014\,x$	0.19	0.03		
44	69	4	None	$y = 2.910 - 0.003\,x$	0.00	0.75	60	$y = 4.367 - 0.022\,x$	0.38	0.00		
45	70	3	None	$y = 2.770 - 0.006\,x$	0.00	0.28	63	$y = 3.249 - 0.013\,x$	0.40	0.00	$y = 3.557\ e^{(-0.006*x)}$	0.42
102	70	2	None	$y = 2.710 + 0.008\,x$	0.00	0.29	50	$y = 3.441 - 0.014\,x$	0.05	0.04		
mean (s.e.)			None				58 (3)					

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is herb cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (herb cover * herb modal height)/spruce total height.

[c] General form of non-linear equation is: $y = a\ e^{(b\,x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

The *Fern* Complex is less widespread than many other vegetation complexes, but in localized wet areas of the ICH zone, it is regarded as a serious threat to conifer performance and a hindrance to the timely achievement of free-growing. This community is commonly treated either manually or with foliar glyphosate to improve light availability in the summer and to reduce damage from falling vegetation in the autumn. Here we discuss fifth-year responses of spruce and the *Fern* Complex to glyphosate treatments applied in August.

Conifer Responses

Foliar glyphosate application reduced the abundance of herbs and shrubs associated with the *Fern* Complex and improved the competitive status of hybrid spruce. This had no effect on seedling survival, which was good (average 93%) in both the treatment and control, but resulted in significant growth improvements within 1–3 years. Seedling height:diameter ratio was significantly lower in the treatment than in the control within 1 year of glyphosate application, and stem diameter, diameter increment, height, and leader length were larger within 3 years. These differences continued to be significant in year 5. Comeau et al. (2000a) similarly found that applying glyphosate at 2.1 kg ai/ha to a shrub-herb community with a substantial fern component improved Engelmann spruce stem diameter and height:diameter ratio. In that study, improvements in seedling performance as a result of chemical brushing were similar to those resulting from two or three manual cuttings. We have not yet used PROBE to study manual brushing of the *Fern* Complex, but studies involving other herb and low-shrub communities have shown that seedlings tend to respond to multiple cuttings (e.g., Comeau et al. 1993) but not to single-entry treatments (e.g., Whitehead and Harper 1998). Wagner et al. (1999) found that the critical period for keeping black spruce seedlings free of bracken-dominated vegetation was between 1 and 3 years after planting.

Although spruce survival was good regardless of brushing, silviculture surveys conducted at the start of this study suggest that considerable mortality occurred between planting and brushing, particularly on one site. Seedlings in this study were 2–4 years old when the *Fern* Complex was brushed, and it is possible that prompt treatment after planting may have improved early survival. The patchy distribution of ferns and spruce seedlings suggested that seedlings had already died in high-density fern patches by the time this study was initiated, which may have led to an underestimation of brushing benefits to conifer survival and growth if brushing had been applied immediately after planting. However, Comeau et al. (2000a) found that brushing a dense herb-shrub community when Engelmann spruce were 1 year old had no effect on 5-year survival, which was high in both the treatments and control. In our study, brushing benefited seedling health by making stems sturdier and allowing them to outgrow bends caused by vegetation- or snow-press within 3 years of treatment. In contrast, control seedlings had only partially outgrown these deformities by year 5.

Brushing the *Fern* Complex with glyphosate reduced overtopping of seedlings that were 2–4 years old at the time of treatment. By year 5, when seedlings were 7–11 years old, only 9% of treated seedlings were still overtopped and almost half were free of vegetation. However, seedlings in the control were also gradually outgrowing the vegetation canopy, and, although only 14% were free of vegetation in year 5, the proportion that were overtopped decreased from 90 to 35% during the 5-year assessment period.

Plant Community Response

Brushing with foliar glyphosate at 1.24–1.78 kg ai/ha in August reduced overall abundance (height and cover) of the *Fern* Complex for at least 5 years, and also had a significant impact on herbs, shrubs, lady fern, and thimbleberry during that period. Other sources also report effective control of lady fern, thimbleberry, and bracken fern following glyphosate application at rates of 1.78–2.1 kg ai/ha (Conard and Emmingham 1983, 1984; Boyd et al. 1985; Thompson 1989; Haeussler et al. 1990). In contrast, manual cutting is known to stimulate rapid regrowth of the dominant species of the *Fern* Complex, with reports of full recovery within one growing season (Haeussler et al. 1990; Hart and Comeau 1992; Comeau et al. 2000a).

Brushing the *Fern* Complex with glyphosate did not reduce richness or diversity of individual species or structural vegetation groups, which agrees with our results for the *Fireweed* Complex (Section 4) and with information from other studies in North America (Haeussler et al. 1999). The chemical treatment did, however, tend to decrease cover of several herb species, including lady fern, bracken, and fireweed. This is to be expected, since the treatment objectives were to reduce the abundance of tall herbs that compete with conifers for light and cause snow- and vegetation-press. However, cover of two berry-producing shrubs (thimbleberry and black huckleberry) also tended to be reduced following the glyphosate treatment, which could have a negative effect on wildlife habitat.

Effects of the Community on Resource Availability

The *Fern* Complex competes with conifers primarily for light, and less so for nutrients and moisture (Haeussler et al. 1990). It may also cause physical damage to seedlings from vegetation-press when dense foliage is shed in the autumn, and from snow-press during the winter. In addition, anecdotal evidence suggests that seedlings growing in high-humidity conditions under dense herb canopies often suffer from fungal infections.

The light saturation point for interior spruce is about 600 μmol m^{-2} s^{-1} (about one-quarter to one-half full sunlight), and the light compensation point is about 100 μmol m^{-2} s^{-1}. Although spruce can survive in dense shade, they become spindly (Binder et al. 1987) and increasingly prone to physical damage. In our study, foliar glyphosate application reduced vegetation abundance and overtopping for at least 5 years, and seedlings responded with increases in diameter and height of 59 and 25%, respectively, and a 20% decrease in height:diameter ratio. Brushing the *Fern* Complex with glyphosate not only resulted in larger, sturdier seedlings, it allowed them to outgrow deformities sooner than in the control by reducing vegetation- and snow-press.

Although we cannot state conclusively that seedling growth improvements were the result of increased light availability, it seems likely. On another ICH site dominated by fireweed, thimbleberry, red raspberry, and bracken, Comeau et al. (1993) found about 63% of the variation in Engelmann spruce shoot growth could be explained by variation in light transmittance through the canopy. The degree of competition experienced by young seedlings under low herb-shrub canopies depends on the species present in the vegetation community, however, and DeLong (1991) showed that light interception by fireweed and lady fern canopies increased dramatically in mid-June, whereas thimbleberry did not intercept a similar amount of light until about 3 weeks later. All three of these species were present in substantial amounts on our study sites. Bracken fern was less common on our sites than lady fern, but it can be locally abundant. Burton (1996) found that the average subcanopy irradiance in bracken patches was 34%, which was the lowest of 13 species assessed in a CWHdm cutblock. We have not yet studied manual cutting of the *Fern* Complex, but it is anticipated that a single pass would result in only short-term increases in light availability, and would be of minimal benefit to seedlings.

Competition Thresholds

A competition threshold for diameter growth of 2- to 4-year-old hybrid spruce was not evident when herb cover was used as a competition index, but was relatively low and fell within a narrow range (58±3) when CRH was used. These results suggest that cover alone was a poor measure of herb competition, and that the relative stature of herbs played an important role in their competitive influence on spruce seedlings. The relative importance of different measures of competition has been used in other studies to infer mechanisms of competition (e.g., Weiner 1982; Newton and Jollife 1998). For example, two-dimensional measures, such as cover or square of distance from target conifers, have been said to imply competition for soil water and nutrients, whereas one-dimensional measures, such as height or angular dispersion, affect light availability (Weiner 1982, 1984). In our study, the greater importance of CRH than cover indices in deriving competition thresholds and predicting spruce diameter supports our assumption that competition on these sites is primarily for light and space, and less so for soil water or nutrients. Nevertheless, these inferences should be used cautiously until controlled studies are conducted that more accurately identify vegetation competition mechanisms, the influences of vegetation on microenvironment, and other biochemical and biological interactions between vegetation and spruce seedlings.

Our data suggest that, above the CRH threshold, interspecific competition was the most important factor limiting tree growth, setting the upper limit for spruce stem diameter. A large proportion of trees (50%) were growing in environments above the threshold, implying that competition continued to constrain many trees in the plantations. Most of the trees above the threshold were control trees that had not been chemically or manually brushed. Below the thresholds, stem diameter was highly variable among both treated and control spruce. Only 7% of treated spruce growing in neighbourhoods below the threshold achieved ≥80% of the maximum diameter measured on the site. This suggests that most trees remained constrained by factors other than fern competition, such as genetics, microenvironment, and biotic factors. Our results suggest that lowering herb abundance to the CRH threshold should reduce competitive constraints and provide the opportunity for greater spruce diameter growth, but that further reductions below the CRH are unlikely to improve spruce growth predictably.

Glyphosate was successful at reducing herb abundance below the CRH threshold for 74% of treated trees during the monitoring period. This corresponded with significant improvements in mean spruce diameter, as well as improved diameter distributions compared with controls. Glyphosate was successful in reducing herb and shrub abundance for at least 5 years. Other studies have shown that glyphosate or repeated manual treatments are necessary in this plant community to reduce competition for the critical-period threshold (Wagner et al. 1999). For example, Comeau et al. (2000a) found that glyphosate application and repeated (three times) manual cutting treatments reduced vegetation cover for 3 years, which resulted in increased diameter growth of spruce seedlings. In contrast, single spring or summer cuttings were ineffective at reducing vegetation abundance for more than one season and had no effect on seedling growth. Single and repeated manual treatments were not tested in our study, but glyphosate was clearly effective in reducing competition levels below the CRH threshold and for the critical period necessary for seedlings to respond.

Our competition threshold results generally agree with Comeau et al. (1993), who found that the relationship between spruce growth and CI (similar to CRH used in this study, where CI = Σ(cover*height for all noncrop species)/spruce height) followed a negative exponential function, with high variation in spruce growth at low levels of CI. In addition, seedling growth was moderately well correlated with light transmittance, suggesting that light competition was an important, but not the only, limitation to seedling growth. Using our "ceiling function" method for identifying competition thresholds from the growth-CI relationship in Comeau et al. (1993), we estimate a CI threshold of approximately 50 (similar to the average CRH threshold in our study). Comeau et al. (1993) found substantial variability in spruce growth and light transmittance below a CI of 150, but nevertheless predict subtantial improvements in seedling growth with lower CIs. Based on the variability below CI = 50 in Comeau et al. (1993) and CRH = 58 in our study, we expect further vegetation reductions below those thresholds to have unpredictable effects on seedling growth responses.

Effectiveness of Treatment at Meeting Management Objectives

The *Fern* Complex is brushed not only to improve conifer survival and growth, but also to ensure that free-growing requirements, as specified by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000), are met in a timely manner. For our *Fern* Complex sites, the Code specifies that target stocking is 1200 (minimum 700) well-spaced conifer stems/ha, and that within 9–15 years of establishment spruce must be at least 1.0 m tall and 100% as high as neighbouring vegetation.

In our study, the fifth-year assessment took place when spruce were 7–9 years-old. On average, seedlings in both the treatment and control met the minimum height and conifer:vegetation height ratio requirements at that time, but fifth-year silviculture survey data show there were significantly more free-growing trees in the treatment (589 stems/ha) than the control (286 stems/ha). Treated seedlings were above brush within the first year of treatment, however, which allowed them to outgrow deformities caused by vegetation-press sooner than those in the control (Figure 53), and may have improved their status in the free-growing assessment.

Although spruce seedling survival has been high since brushing (average 93% in the treatment and control), our silviculture survey information suggests that well-spaced stocking may drop below the minimum requirement. There appears to have been considerable seedling mortality (mainly on one site) between planting and the application of chemical brushing treatments. Further study is required to determine whether early spruce survival in the *Fern* Complex can be improved with the prompt application of brushing treatments following planting.

A single glyphosate treatment improved all aspects of 2- to 4-year-old spruce seedling growth, and is also predicted to allow them to reach free-growing sooner than control seedlings. Competitive status, vigour, and growth rates of control seedlings were also gradually improving, however, and it is unknown whether the advantage conferred by brushing will be sustained. The effects on long-term yield can be determined only through continued monitoring.

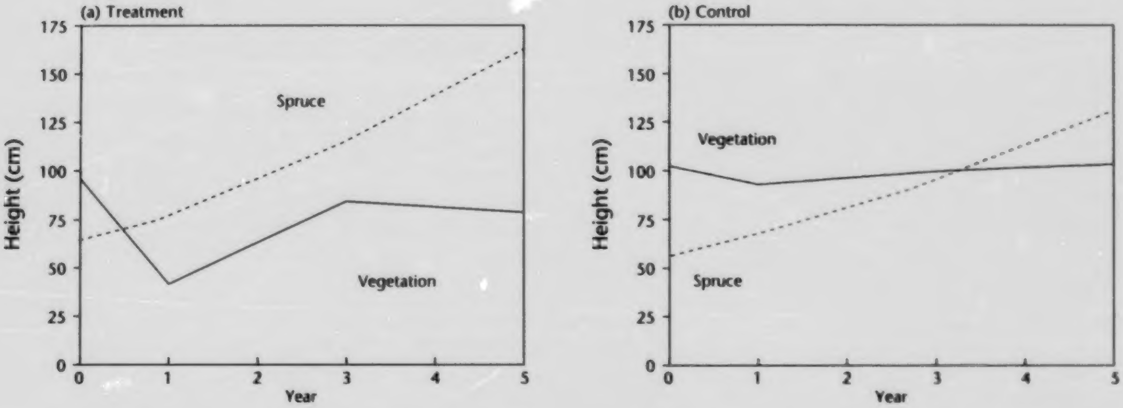


FIGURE 53 *Comparison of average hybrid spruce and vegetation height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH* Fern *Complex. Values for years 2 and 4 were interpolated from actual data. Spruce in the treatment were taller than vegetation within 1 year of the cutting treatment, and those in the control outgrew the vegetation canopy after year 3.*

CONCLUSION

Brushing with glyphosate reduced overall cover and height of the *Fern* Complex by 41 and 51%, respectively, in the first year after treatment, and the abundance of individual species such as lady fern and thimbleberry by much more. After 5 years, treated vegetation had still not recovered to control levels. Chemical treatment did not affect the richness or diversity of individual species of structural vegetation groups, however. Spruce seedling stem diameter and height growth increased by 59 and 25%, respectively, during the 5-year monitoring period, and height:diameter ratio decreased by 20%. The application of glyphosate had no effect on seedling survival, which averaged 93% regardless of brushing. Brushing treatments were not applied until spruce were 2–4 years old, however, and silviculture survey information suggests that considerable mortality had occurred in the interval between planting and brushing. Low stocking is likely to interfere with the average ability of our sites to meet free-growing.

Although brushing improved growth of hybrid spruce seedlings, it did not contribute to the ultimate achievement of free-growing status within the assessment window. Both treated and control seedlings met the minimum height and conifer: vegetation height ratio requirements within the required time (B.C. Ministry of Forests 2000), and brushing was unable to address low stocking because it was applied after a great deal of mortality had already occurred (mainly on one site).

MANAGEMENT IMPLICATIONS

1. Two- to 4-year-old spruce seedlings growing among an abundant *Fern* Complex (70–95% cover of 1-m-tall vegetation) did not require brushing to maintain acceptable survival. However, mortality and loss of vigour apparently occurred in the delay between planting and brushing, probably because of the rapid and severe onset of competitive stress that is characteristic of this complex. To avoid this problem, we recommend planting seedlings within 1–2 years of harvest and/or site preparation, and brushing within 1–2 years of planting.
2. Our results show that brushing an abundant *Fern* Complex with glyphosate improved spruce diameter and height growth and reduced height:diameter ratio, resulting in stockier seedlings that were presumably more resistant to damage from vegetation- and snow-press. It is not known whether these short-term growth increases will result in better performance over the long term.
3. The application of glyphosate at 1.24–1.78 kg ai/ha reduced abundance of the *Fern* Complex for at least 5 years. This did not reduce richness or diversity of individual species or structural vegetation groups, but it did reduce abundance of two berry-producing shrubs that are important to wildlife (black huckleberry and thimbleberry).
4. A competition threshold for spruce diameter growth was not evident where herb cover was used as a competition index, but was 58 where CRH was used. Reducing herb abundance below the CRH threshold for a 3-year period should improve spruce diameter growth. The ability to identify CRH thresholds but not cover thresholds suggests that the *Fern* Complex affects spruce growth more by reducing light than by reducing soil resource availability.
5. We predict brushing the *Fern* Complex with glyphosate will not prove necessary for seedlings to meet the minimum height and conifer:vegetation height ratio requirements for free-growing (B.C. Ministry of Forests 2000) in our study. Brushing did not improve spruce seedling survival, which was low, on average, at the time brushing treatments were applied. We expect that even minimum stocking standards may not be met, but earlier brushing may have offset this problem.

SECTION 6

Mixed Shrub Complex

ABSTRACT

The effects of manual cutting and sheep grazing on newly planted to 3-year-old spruce seedlings and the *Mixed Shrub* Complex were examined in the ICH and ESSF zones for 1–3 years. Prior to treatment, vegetation averaged 80–90 cm tall with 80–90% total cover.

Manual cutting slightly reduced abundance of the *Mixed Shrub* Complex for 1 year, after which treatment effects disappeared. Three years after brushing, spruce survival was moderate in both the treatment and control (average 75%), and most mortality was due to vegetation competition. Surviving seedlings in the cutting treatment had slightly larger stem diameters (1.58 versus 1.28 cm) and smaller height:diameter ratio (54.8 versus 63.3) than those in the control by year 3. Height and leader length were unaffected by the cutting treatment. Sheep grazing had no effect on overall vegetation abundance, but it reduced fireweed cover and height for at least 1 year. It did not improve either survival (average 94%) or growth of spruce seedlings, which were good in both the treatment and control. Sheep trampled seedlings at one site, causing a slight reduction in seedling survival and vigour. Neither manual cutting nor sheep grazing affected richness or diversity of individual species or structural vegetation groups.

The competition threshold for stem diameter of newly planted to 3-year-old Douglas-fir, hybrid spruce, and western redcedar averaged 74% shrub cover, and did not vary among conifer species. When CRH was used as the index, thresholds were 48, 84, and 187 for Douglas-fir, hybrid spruce, and western redcedar, respectively. The results suggest that cover alone is a poor measure of competition in the *Mixed Shrub* Complex, but that reducing vegetation abundance below CRH thresholds may improve spruce seedling performance.

Single manual cutting and grazing treatments are not expected to influence the achievement of free-growing (B.C. Ministry of Forests 2000) on our sites. Survival and conifer height growth were adequate, on average, in both the treatment and control to allow requirements to be met.

Description of the *Mixed Shrub* Complex

The *Mixed Shrub* Complex is typically a lush mixture of several shrub and herb species (Figure 54). Common shrub species are thimbleberry (*Rubus parviflorus*), red raspberry (*Rubus idaeus*), falsebox (*Pachistima mysinites*), black twinberry (*Lonicera involucrata*), red elderberry (*Sambucus racemosa*), devil's club (*Oplopanax horridus*), false azalea (*Menziesia ferruginea*), red-osier dogwood (*Cornus sericea*), Douglas maple (*Acer glabrum*), willow (*Salix* spp.), and Sitka alder (*Alnus viridis*). Common herb species include fireweed (*Epilobium angustifolium*), lady fern (*Athyrium filix-femina*), bracken (*Pteridium aquilinum*), and grasses. Not all of these shrub and herb species are present on every site (Boateng and Comeau 1997g). The *Mixed Shrub* Complex often includes the same species found in the *Fireweed* or *Fern* complexes, but as long as shrubs dominate the plant community, it is classified as *Mixed Shrub*.

In the southern interior of British Columbia, the *Mixed Shrub* Complex is common on moist to wet sites in the ICH zone, including those that are transitional to the ESSF. The complex is often found on sites where conifer growth is highly productive (Boateng and Comeau 1997g).

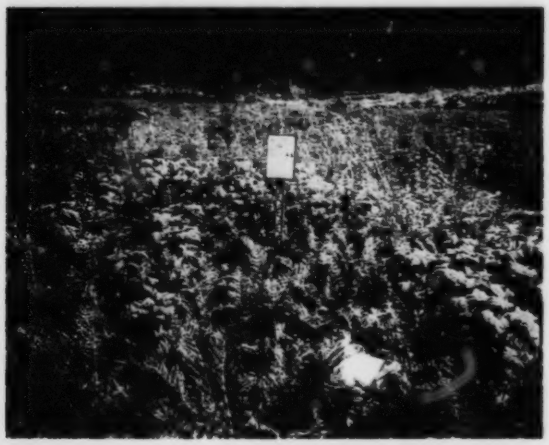


FIGURE 54 *The Mixed Shrub Complex prior to manual cutting at Westfall River (Site 123) in the ESSFwc1 variant in the Kootenay Lake Forest District. Photo credit: JMJ Holdings Inc.*

Development of the *Mixed Shrub* Complex

The *Mixed Shrub* Complex is comprised of a variety of plant species, which regenerate by various strategies following logging. Some shrub species produce abundant berries that are dispersed by animals (e.g., thimbleberry, raspberry, red-osier dogwood, and twinberry). Seeds of these species are often banked in the soil before logging, and then germinate when conditions become suitable, such as after canopy removal or ground disturbance. Other species, including fireweed, alder, and willow, have light, short-lived seed that is blown in from adjacent areas. All of the major species in the complex regenerate vegetatively, but the rate of spread varies among species. Thimbleberry, raspberry, falsebox, fireweed, and bracken have rapidly spreading rhizomes or root suckers. Red-osier dogwood and black twinberry spread more slowly by layering or limited rhizomatous growth. Douglas maple, alder, willow, red elderberry, and false azalea sprout from the root collar, often creating multistemmed bushes (Haeussler et al. 1990; Boateng and Comeau 1997g).

Overstorey removal increases the cover of many species that make up the *Mixed Shrub* Complex (e.g., thimbleberry, red raspberry, red elderberry, Sitka alder, willow, fireweed, and bracken), but has minimal or variable effect on other species (e.g., black twinberry, false azalea, Douglas maple, and lady fern) (Haeussler et al. 1990).

Light to moderate burns tend to encourage vigorous development of the *Mixed Shrub* Complex by stimulating regrowth and providing suitable seedbeds for germination of banked or new seed (Comeau and Boateng 1997g). Intense burns can hinder development of the *Mixed Shrub* Complex by killing root systems, but such burns are generally not achieved on the moist or wet sites where this plant community is found. Low-impact soil disturbance, either from logging or mechanical site preparation (MSP), favours development of the *Mixed Shrub* Complex by allowing many species to regenerate vegetatively. High-impact MSP may hinder development of the complex by destroying roots and rhizomes in the upper soil horizons, and thereby limiting vegetative reproduction (Boateng and Comeau 1997g).

Invasion of the *Mixed Shrub* Complex is usually rapid following disturbance because it develops on highly productive sites and because plant species are usually abundant before logging. Within 1–2 years following harvesting, the plant community can reach 100% cover and a height of 1–1.5 m (Boateng and Comeau 1997g).

Interactions with Conifer Seedlings

The *Mixed Shrub* Complex is considered a serious threat to the survival and growth of young conifers because it tends to occur on highly productive sites where plant growth is vigorous. The *Mixed Shrub* Complex appears to compete with conifers mainly by reducing available light; competition for moisture and nutrients is probably of minor importance because it typically occurs on wet, rich sites (Boateng and Comeau 1997g). Mechanical damage from vegetation- and snow-press can also impede conifer performance (Hart and Comeau 1992). For example, Thompson et al. (1998) found that snow-press damage to Douglas-fir was twice as common in untreated *Mixed Shrub* communities as manually brushed areas.

Importance to Wildlife and Range

Most of the plant species that make up the *Mixed Shrub* Complex are valuable to wildlife. The more diverse the species composition, the greater the number and variety of animals that are associated with the complex (Boateng and Comeau 1997g). Many of the shrubs (e.g., thimbleberry, red raspberry, elderberry, red-osier dogwood, and black twinberry) produce abundant berry crops, which are readily eaten by black and grizzly bears, small mammals, and many birds. The stems and shoots of several species (e.g., willow, Douglas maple, red-osier dogwood, and elderberry) are important food sources for ungulates including deer, moose, elk, and caribou. The leaves of some species (e.g., red raspberry, thimbleberry, Douglas maple, and lady fern) are browsed by ungulates and some other mammals. The dense vegetation typical of the *Mixed Shrub* Complex provides cover for many small mammals, and the larger shrubs (e.g., willow and elderberry) provide nest sites for birds (Haeussler et al. 1990).

The value of the *Mixed Shrub* Complex to livestock depends on its species composition. Fireweed and willow are highly palatable to sheep but alder, elderberry, thimbleberry, red raspberry, falsebox, and bracken tend to be grazed erratically or not at all (Newsome et al. 1995).

Common Brushing Treatments in the *Mixed Shrub* Complex

The *Mixed Shrub* Complex is commonly brushed to release conifer seedlings in the interior wet belt of British Columbia. Table 46 lists the brushing treatments that are commonly applied. Brushing is usually done when plantations are young (1–5 years old) and still overtopped by vegetation. The most common brushing treatments are manual cutting and ground- or, to a lesser degree, aerial-foliar glyphosate application. Grazing is sometimes used where slash levels are low, slopes are gentle, and vegetation is less than 1 m tall. Glyphosate controls many of the species found in the *Mixed Shrub* Complex. Manual cutting and grazing treatments are usually applied at least twice, whereas glyphosate is generally applied once. Manual cutting and ground-foliar glyphosate are applied either as broadcast or spot treatments. Manual brushing is done with a variety of tools that cut or bend vegetation (Table 46). Motorized brush saws are commonly used, but have the potential to damage seedlings hidden in dense vegetation.

TABLE 46 *Common brushing treatments applied to the* Mixed Shrub *Complex in the southern interior of British Columbia*

Treatment	Objective	Optimum timing	Suggested number of treatments	Tools	Average cost per ha[a]	Potential disadvantage
Manual cutting	1. Reduce competition for light 2. Increase soil warming (ESSF) 3. Reduce snow- and vegetation-press	Mid- to late spring or spring and mid-summer[b]	2–3[b]	1. Motorized brush saw 2. Machete 3. Sandvik 4. Weed whip	$538 $511 $511 $511	1. Treatment damage to seedlings 2. Multiple treatments are expensive
Sheep grazing	1. Reduce competition for light 2. Increase soil warming (ESSF) 3. Reduce snow- and vegetation-press	Spring	2–3	1. Sheep	$248	1. Potential for seedling damage if flocks are not properly managed
Glyphosate (2.1 kg ai/ha)	1. Reduce competition for light 2. Increase soil warming (ESSF) 3. Reduce snow- and vegetation-presss	Mid- to late August[c]	1	1. Backpack sprayer 2. Fixed-wing plane or helicopter (aerial)	$700 $311	1. Difficulties obtaining herbicide permits 2. Shifts in species composition

[a] Based on average costs for the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)
[b] Comeau et al. (2000a)
[c] P. Comeau, pers. comm., 2000

Conifer and vegetation responses to manual cutting and sheep grazing of the *Mixed Shrub* Complex are presented below.

Manual Cutting

Hybrid spruce in the ICH and ESSF zones

This section describes third-year hybrid spruce and vegetation responses to manual cutting of the *Mixed Shrub* Complex in the ICH and ESSF zones (n = 3). Seedlings were from 0 (newly planted) to 3 years old at the time of treatment. The ICH and ESSF zones were combined in this analysis because the vegetation and environmental conditions were reasonably similar.

Description of study sites and treatments

The three sites in this treatment cell are widely distributed throughout the Kamloops and Nelson forest regions. The Brash Creek site is located 18 km northeast of Enderby in the Salmon Arm District, the Finn Creek site is 24 km northeast of Avola in the Clearwater District, and the Westfall River site is north of Kaslo in the Kootenay Lake District. The Brash Creek site occurs in the Northern Monashee Wet Cold variant (ESSFwc2), the Finn Creek site in the Mica Very Wet Cool ICH variant (ICHvk1), and the Westfall River site in the Columbia Wet Cold ESSF variant (ESSFwc1).

Physiographic features varied among the sites (Table 47). The Brash Creek site is classified as site series 06 (subhygric) with a mid-slope position, 20% northwesterly aspect, Brunisolic sandy loam soil, and an elevation of 1450 m. Finn Creek is classified as site series 01 (mesic), with a lower slope position, 20% east aspect, Brunisolic silt clay loam soil, and an elevation of 500 m. Westfall River is classified as site series 01 (mesic), with a mid-slope position, 5% south aspect, Luvisolic silt loam soil, and an elevation of 1150 m.

The three stands have similar histories; they were clearcut between 1989 and 1991 and burned either the same or the following year. On all three sites, planting with spruce took place within 1–3 years of burning. Survival was poor at the Finn Creek site and it was replanted in 1992 and again in 1994. On all three sites, brushing was carried out, and PROBE was initiated, when spruce were newly planted to 3 years old. At the time of brushing, seedlings averaged 19–58 cm tall and were growing amidst 75–87% vegetation cover of average height 78–97 cm. Nearly all spruce were either overtopped or threatened by surrounding vegetation. Thimbleberry and lady fern were the dominant species, but raspberry and fireweed were also common. When PROBE was initiated, the sites were stocked with a total of 1214–1639 conifer stems/ha, of which 1050–1159 stems/ha were well spaced.

Each site received only a single brushing treatment that was applied in July or August (Table 48). Vegetation was brushed within 0.75–1.5 m of crop trees using motorized brush saws, brush blades, or weed whips.

Conifer responses

Survival and vigour There was no significant difference in third-year survival of 3- to 6-year-old spruce (0–3 years old at the time of treatment) between the manual cutting treatment and control (p>0.10) (Table 49). Survival was excellent (average 97%) 1 year after brushing, but by year 3, it was reduced to an average of 75%. Competition from the *Mixed Shrub* Complex was the cause of nearly all the spruce seedling mortality in both the treatment and control, with only minor amounts (1–3%) attributed to cattle and unknown causes.

Average vigour of surviving spruce seedlings declined very slightly in the control relative to the treatment during the 3 years of this study. At the time of brushing, an average 6% of seedlings were of poor vigour; by year 3 the proportion of poor-vigour seedlings had increased to 18% in the control versus 8% in the treatment (Figure 55).

Growth Spruce seedling stem diameter improved within 1 year of the *Mixed Shrub* Complex being manually cut (p = 0.06) (Table 49, Figure 56), and by year 3, treated seedlings had 23% larger stem diameter than control seedlings (1.58 versus 1.28 cm, p = 0.02). Stem diameter increment was also larger in the cutting treatment than the control in year 3 (0.29 versus 0.21 cm, p = 0.03). Manual cutting had no significant effect on seedling height or leader length, but height:diameter ratio was lower in the treatment than the control

TABLE 47 *Characteristics and history of the three replicate study sites where the ICH/ESSF* Mixed Shrub *Complex was manually cut in hybrid spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Brash Creek PROBE 42 Salmon Arm District	ESSFwc2 06 (subhygric)	1450	NW 20%	Brunisol/ sandy loam	Clearcut 1989 Burned 1989	4	4	1	P 1990	PSB 313B	3	58 (12)	Thimbleberry cover: 24 (16) Thimbleberry height: 60 (19) Fireweed cover: 9 (13) Fireweed height: 83 (16) Valerian cover: 7 (9) Valerian height: 29 (13) All veg. cover: 75 (15) All veg. height: 78 (22)	1214	1050
Finn Creek PROBE 60 Clearwater District	ICHvk1 01 (mesic)	500	E 20%	Brunisol/ silt clay loam	Clearcut 1989–1990 Burned 1991	5	4	3	P 1991 P 1992 P 1994	PBR 415B 1+1	1	19 (3)	Lady fern cover: 37 (21) Lady fern height: 98 (21) Thimbleberry height: 74 (38) Thimbleberry cover: 21 (18) Raspberry cover: 14 (14) Raspberry height: 61 (36) Fireweed cover: 5 (5) Fireweed height: 71 (53) All veg. cover: 87 (13) All veg. height: 97 (21)	1639	1067
Westfall River PROBE 123 Kootenay Lake District	ESSFwc1 01 (mesic)	1150	S 5%	Luvisol/ silt loam	Clearcut 1991 Burned 1992	2	1	1	P 1993	PSB 415D 2+0	0	38 (6)	Thimbleberry cover: 48 (22) Thimbleberry height: 72 (15) Lady fern cover: 25 (18) Lady fern height: 71 (11) All veg. cover: 81 (12) All veg. height: 79 (14)	1336	1159

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 48 *A description of manual cutting treatments applied to the three replicate study sites to release hybrid spruce seedlings growing in the ICH/ESSF* Mixed Shrub Complex

Site	Initial treatment date	Treatment radius	Treatment tool	Repeat treatment
Brash Creek	Late August 1993	0.75 m	Brush blade	None
Finn Creek	July 1995	1.0 m	Brush saw	None
Westfall River	August 1993	1.0–1.5 m	Weed whip	None

TABLE 49 *Survival and growth responses of hybrid spruce seedlings to manual cutting in the ESSF/ICH* Mixed Shrub Complex

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	96	97	1.731	0.74
3 yr post-treatment	79	71	9.443	0.63
Stem diameter (cm)				
Pre-treatment	0.68	0.64	0.021	0.31
1 yr post-treatment	0.94	0.85	0.016	0.06*
3 yr post-treatment	1.58	1.28	0.030	0.02*
Diameter increment (cm)				
1 yr post-treatment	0.27	0.22	0.015	0.12
3 yr post-treatment	0.29	0.21	0.011	0.03*
Height (cm)				
Pre-treatment	38.6	38.3	0.216	0.46
1 yr post-treatment	50.1	51.6	0.619	0.24
3 yr post-treatment	80.9	74.5	2.989	0.27
Leader length (cm)				
Pre-treatment	14.0	14.1	0.453	0.84
1 yr post-treatment	8.2	9.1	0.410	0.24
3 yr post-treatment	14.1	12.2	0.724	0.21
Height:diameter ratio				
Pre-treatment	57.3	59.6	1.510	0.40
1 yr post-treatment	57.7	65.8	1.380	0.05*
3 yr post-treatment	54.8	63.3	0.893	0.02*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

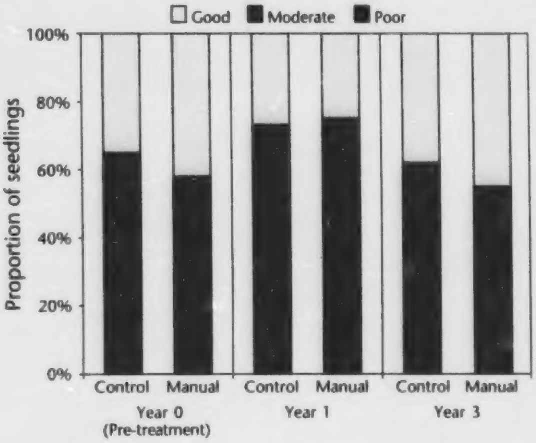


FIGURE 55 *Comparison of hybrid spruce vigour between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ICH/ESSF* Mixed Shrub Complex. *Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

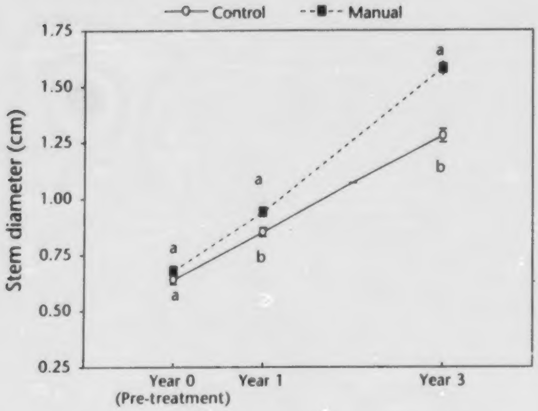


FIGURE 56 *Comparison of hybrid spruce stem diameter between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ICH/ESSF* Mixed Shrub *Complex. Error bars represent one standard error of the mean* ($\bar{y}$) *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* ($\propto = 0.10$).

in both the first and third years after brushing (54.8 versus 63.3 in year 3, p = 0.02).

Standardized spruce stem diameter distributions became increasingly normal in the treatment and control between the pre-treatment and third-year assessments (Figure 57). By year 3, there were slightly higher frequencies in the +1.5 to +2.5 classes in the treatment than in the control, which corresponds with ANOVA results showing stem diameter improved in years 1 and 3 in response to treatment. The trend of increase shown by the diameter distributions is slight, however, and may not continue because the vegetation community recovered quickly from the cutting treatment. Height distributions were approximately normal, and were similar in the treatment and control throughout the 3-year measurement period (Figure 58). This is consistent with ANOVA results showing that spruce height did not increase as a result of manual cutting in the *Mixed Shrub* Complex.

Competitive status Three years after brushing, when seedlings were 3–6 years old, fewer than 10% were free of vegetation in either the treatment or control (Figure 59). However, the competitive status of many spruce seedlings in both the treatment and control improved from "overtopped" to "threatened" during the monitoring period. The competitive status of treated seedlings was slightly better than that of control seedlings in year 3: 37% of treated seedlings were overtopped compared to 52% of control seedlings, and 56% of treated seedlings were threatened compared to 39% of control seedlings.

Plant community responses

Abundance Manual cutting caused only minor and short-lived reductions in abundance of the *Mixed Shrub* Complex (Table 50, Figure 60). One year after cutting, shrub cover was 40.6% in the treatment versus 50.4% in the control (p = 0.07), but the difference disappeared by year 3. Shrub height was not reduced by the cutting treatment in either year 1 or 3. Covariance analysis was applied to shrub cover and height data because of pre-treatment differences between the treatment and control. Overall vegetation height was reduced slightly in the treatment relative to the control in year 1 (93.2 versus 97.4 cm, p = 0.08), but again, the difference disappeared by year 3. Herb cover increased temporarily in response to manual cutting (57.6% in the treatment versus 48.8% in the control in year 1, p = 0.06).

Richness and diversity of individual species and structural vegetation groups Manual cutting had no effect on the richness of individual plant species; there were an average of 34 species prior to brushing and 38 species 3 years later, but the increases occurred similarly in the treatment and control. Brushing resulted in a slight reduction in species diversity in year 3 (SDI of 0.73 in treatment versus 0.82 in control, p = 0.06) (Table 51). No differences were found in the richness or diversity of structural vegetation groups as a result of brushing (p>0.10) (Table 52).

Reductions in the relative abundance of several individual shrub and herb species occurred following manual cutting (Table 53). Among shrubs, cover of thimbleberry, elderberry, and black huckleberry was reduced in the treatment relative to the control on at least two of three sites. The following herbs decreased in cover on at least two sites: spiny wood fern (*Dryopteris expansa*), oak fern (*Gymnocarpium dryopteris*), small twistedstalk (*Streptopus streptopoides*), and dandelion (*Taraxacum officinale*).

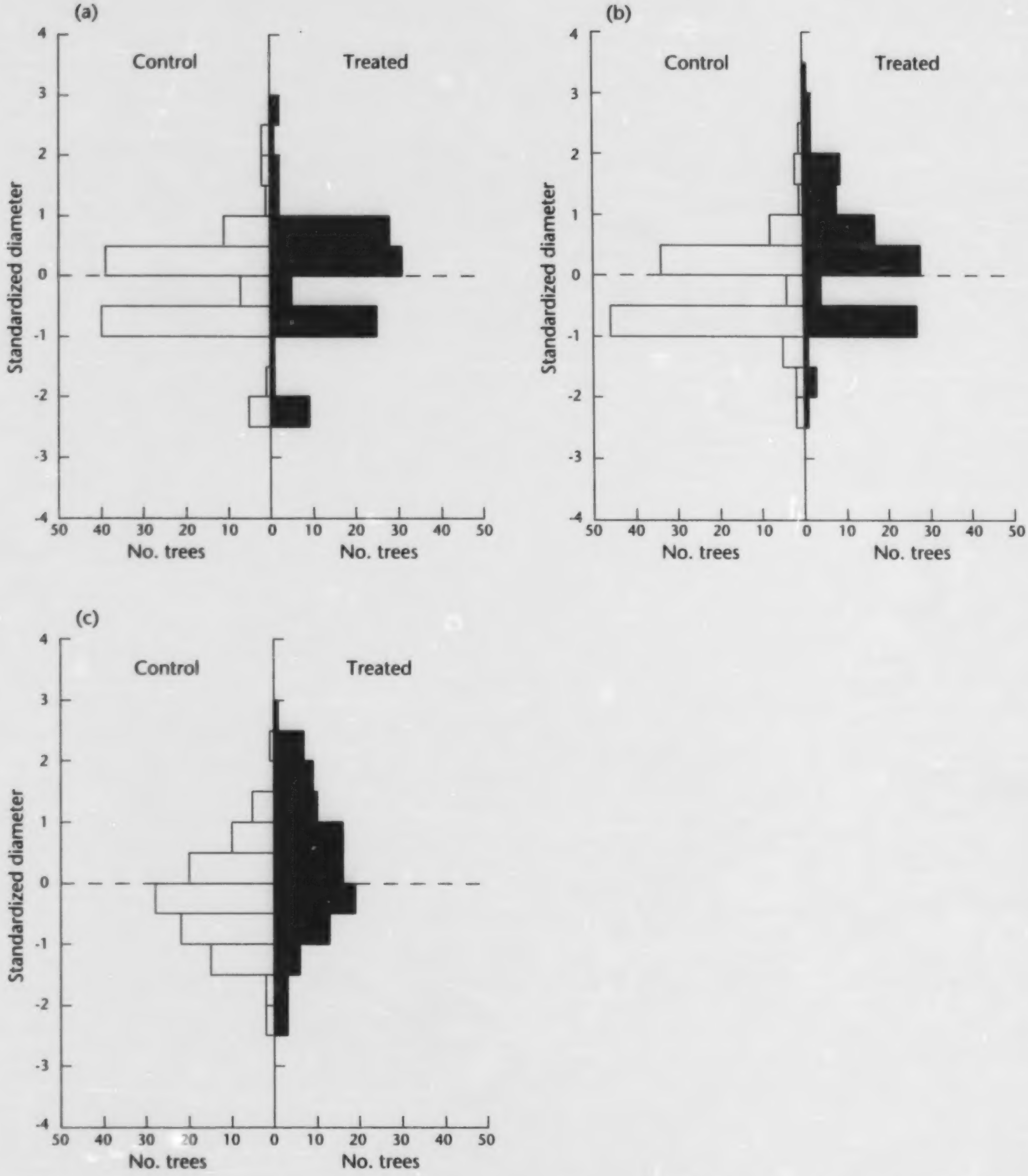


FIGURE 57 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH* Mixed Shrub *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

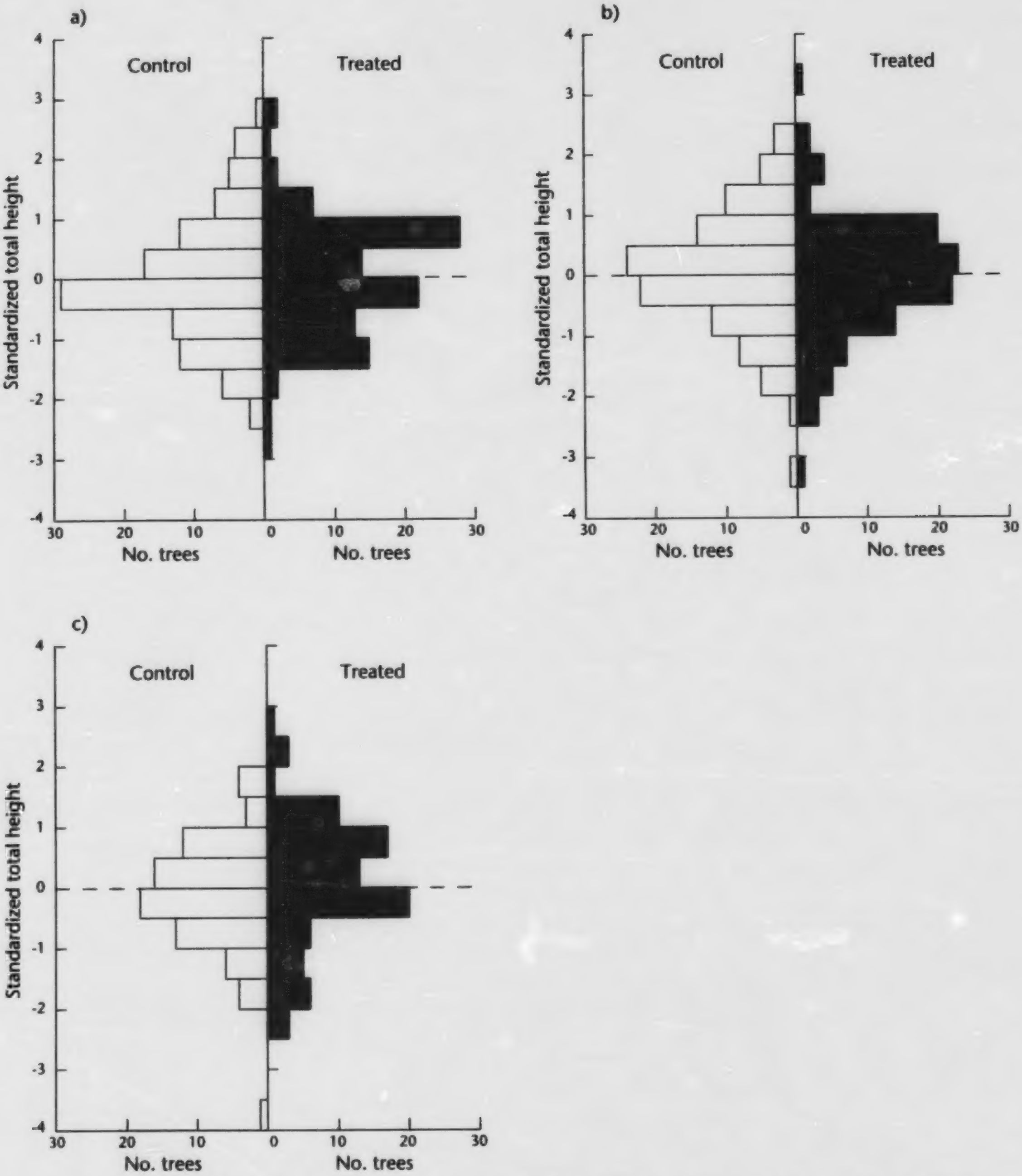


FIGURE 58 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH Mixed Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

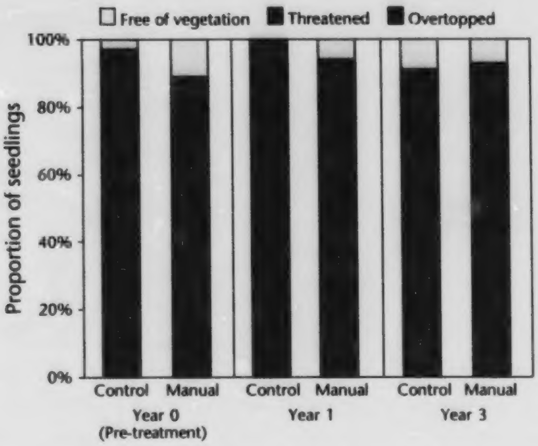


FIGURE 59 *Comparison of hybrid spruce competitive status between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ICH/ESSF* Mixed Shrub *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

TABLE 50 *Cover and height of vegetation in the ICH/ESSF* Mixed Shrub *Complex before and after manual cutting in hybrid spruce plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
All vegetation				
Cover (%)				
Pre-treatment	81.3	81.3	3.841	1.00
1 yr post-treatment	88.4	89.8	1.081	0.46
3 yr post-treatment	87.4	85.8	2.898	0.74
Height (cm)				
Pre-treatment	80.7	88.4	2.179	0.13
1 yr post-treatment	93.2	97.4	0.899	0.08*
3 yr post-treatment	94.7	98.9	1.567	0.20
Shrubs				
Cover (%)				
Pre-treatment	37.3	50.5	2.655	0.07*
1 yr post-treatment	40.6	50.4	0.423	0.07*
3 yr post-treatment	41.8	52.2	1.561	0.54
Height (cm)				
Pre-treatment	71.0	84.0	1.399	0.02*
1 yr post-treatment	81.5	88.0	2.527	0.80
3 yr post-treatment	88.3	87.1	6.152	0.90
Herbs				
Cover (%)				
Pre-treatment	56.6	46.3	3.012	0.14
1 yr post-treatment	57.6	48.8	1.591	0.06*
3 yr post-treatment	59.9	56.8	4.753	0.69
Height (cm)				
Pre-treatment	80.7	82.2	1.480	0.56
1 yr post-treatment	97.1	106.8	3.176	0.16
3 yr post-treatment	90.5	98.7	3.226	0.22

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 4. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

The overall abundance of grasses also decreased. The only species that tended to increase in abundance following manual cutting of the *Mixed Shrub* Complex was three-leaved foamflower (*Tiarella trifoliata*).

Sheep Grazing

Hybrid spruce in the ICH and ESSF zones

This section describes first-year hybrid spruce and vegetation responses to sheep grazing of the *Mixed Shrub* Complex in the ICH and ESSF zones (n = 3) (Figure 61). Seedlings were 1–2 years old at the time of treatment.

Description of study sites and treatments

All three sites in this treatment cell are located in the Clearwater District of the Kamloops Forest Region. The Doug Creek site is located west of Blue River, and the Upper and Lower Saskum Plateau sites are located 25–30 km southeast of Clearwater. The Doug Creek site is located in the Northern Monashee Wet Cold ESSF variant (ESSFwc2), and the Saskum Plateau sites occur in the Thompson Moist Warm ICH variant (ICHmw3). These ICH and ESSF sites were combined in a single analysis because of the close similarity in plant community composition.

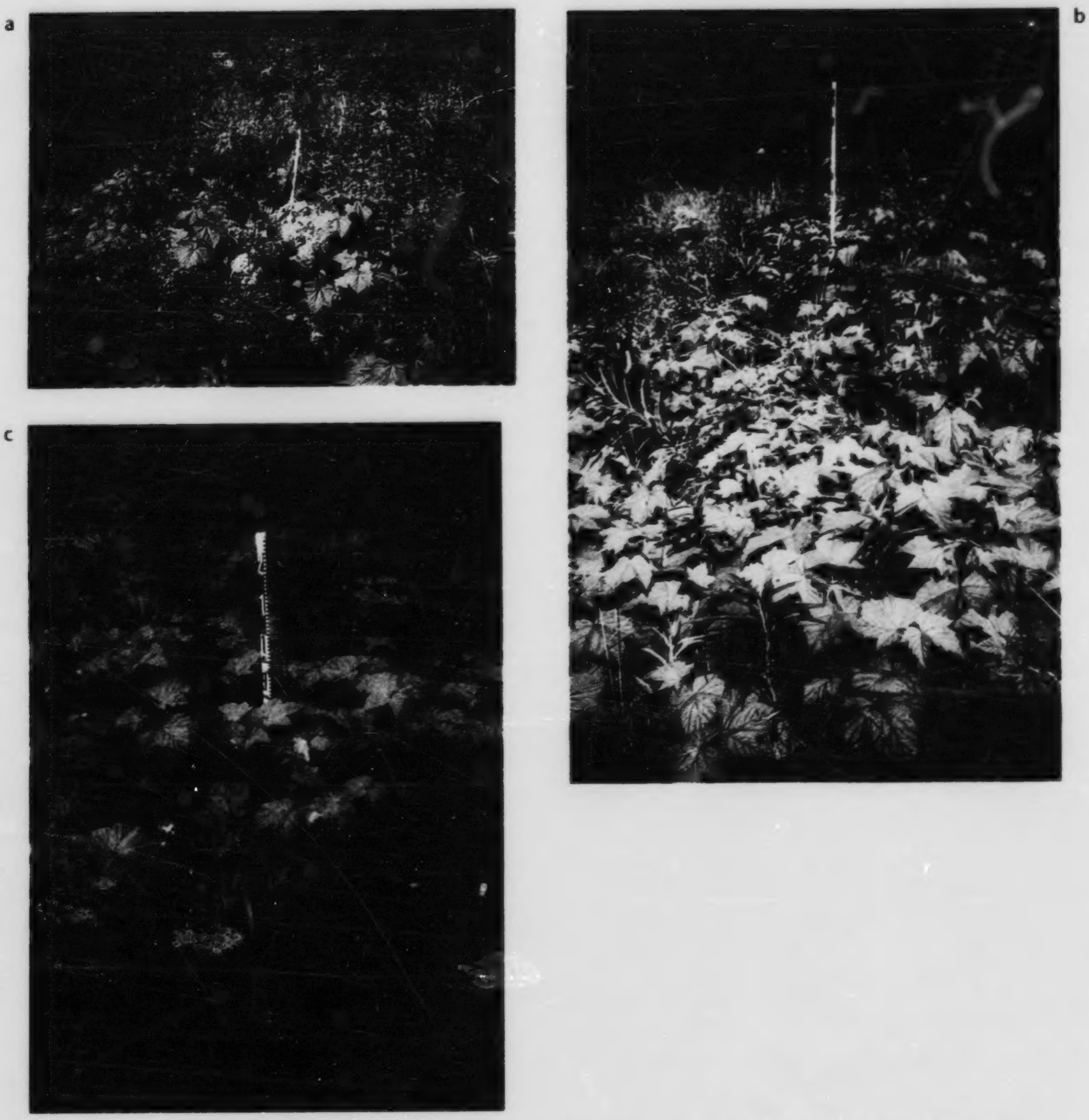


FIGURE 60 *Effects of manual cutting on the* Mixed Shrub Complex *(a) 1 year and (b) 3 years following treatment. The control (c) is shown 3 years post-treatment for comparison. The plant community had recovered to control levels by 3 years post-treatment. Photo credit: JMJ Holdings Inc.*

TABLE 51 *Richness and diversity of vascular plant species in the ICH/ESSF Mixed Shrub Complex before and after manual cutting in hybrid spruce plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	32.33	35.00	3.274	0.62
1 yr post-treatment	38.33	38.00	3.009	0.94
3 yr post-treatment	39.33	36.33	3.559	0.61
Shannon-Weaver Diversity Index				
Pre-treatment	2.25	2.26	0.113	0.93
1 yr post-treatment	2.20	2.30	0.249	0.80
3 yr post-treatment	2.05	2.29	0.072	0.15
Simpson's Diversity Index				
Pre-treatment	0.80	0.82	0.044	0.73
1 yr post-treatment	0.78	0.78	0.074	0.99
3 yr post-treatment	0.73	0.82	0.014	0.06*

p-value denoted with "*" is significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 52 *Richness and diversity of structural vegetation groups in the ICH/ESSF Mixed Shrub Complex before and after manual cutting in hybrid spruce plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	5.00	5.00	0.000	1.00
1 yr post-treatment	5.00	5.00	0.000	1.00
3 yr post-treatment	5.00	5.33	0.236	0.42
Shannon-Weaver Diversity Index				
Pre-treatment	1.09	1.07	0.054	0.86
1 yr post-treatment	1.02	1.07	0.089	0.73
3 yr post-treatment	1.02	1.13	0.065	0.37
Simpson's Diversity Index				
Pre-treatment	0.61	0.60	0.040	0.86
1 yr post-treatment	0.58	0.60	0.055	0.81
3 yr post-treatment	0.56	0.63	0.034	0.31

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 53 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH/ESSF Mixed Shrub Complex in hybrid spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Tall shrubs			*Alnus viridis*
Low shrubs		*Rubus parviflorus* *Sambucus racemosa* *Vaccinium membranaceum*	*Rubus idaeus*
Herbs	*Tiarella trifoliata*	*Dryopteris expansa* Grass spp. *Gymnocarpium dryopteris* *Streptopus streptopoides* *Taraxacum officinale*	*Carex* spp. *Epilobium ciliatum* *Mitella* spp. *Osmorhiza chilensis* *Rubus pedatus* *Smilacina racemosa* *Streptopus roseus* *Viola* spp.

FIGURE 61 *The Mixed Shrub Complex prior to sheep grazing at Doug Creek (Site 38) in the ESSFwc2 variant in the Clearwater Forest District. Photo credit: Silver Ring Forestry Ltd.*

The Doug Creek site is classified as site series 07 (subhygric), with a lower slope position, a steep (50%) west aspect, and loamy Podzolic soil (Table 54). The two Saskum Plateau sites are physiographically similar. They are classified as site series 01 (mesic), with moderate (15–30%) northerly slopes, elevations of 1250–1350 m, and clay loam Brunisolic soils.

The original stands were clearcut in 1971 at Doug Creek and 1993 at the two Saskum Plateau sites. Broadcast burning was done within 1 year of logging at each site. Spruce was planted 22 years after burning at Doug Creek and 4 years after burning at the Saskum Plateau sites. The Doug Creek site was grazed by sheep for site preparation immediately before planting, whereas the Saskum Plateau sites were not. At all three sites, sheep grazing was employed as a brushing treatment and PROBE trials were initiated 1–2 years after planting.

At the time of brushing, spruce at Doug Creek averaged 16 cm tall (12% of vegetation height), and at the two Saskum Plateau sites they averaged 34 cm tall (52–54% of vegetation height). Total conifer stocking at the time of brushing was 1192–1478 stems/ha, of which an average 1060 stems/ha were well spaced, with no significant difference between the treatment and the control (p = 0.79).

Vegetation was dense and tall at Doug Creek before grazing (99% cover and 130 cm height). The dominant species at this site were thimbleberry, fireweed, and lady fern. Vegetation at the Saskum Plateau sites averaged 83–85% cover and 60–65 cm in height. The dominant species at these sites were thimbleberry, fireweed, and red raspberry. Sheep grazing took place in August at the Doug Creek site, and June at the Upper Saskum Plateau and Lower Saskum Plateau sites (Table 55).

Conifer response

Survival and vigour Survival of 2- to 3-year-old spruce (1–2 years old at the time of treatment) was good (average 94%) in the control and grazing treatment after 1 year (p = 0.23) (Table 56). Average seedling vigour declined in both the grazing treatment and control within 1 year of grazing (Figure 62). The percentage of poor-vigour seedlings increased from 7 to 27% in the grazing treatment and from 4 to 21% in the control, while the percentage of good-vigour seedlings remained constant throughout. The principal causes of mortality and reduced vigour were vegetation competition in the control and trampling in the grazing treatment. Trampling occurred mainly at one site (Doug Creek).

Growth There were no differences in spruce stem diameter, diameter increment, total height, leader length, or height:diameter ratio between the grazing treatment and control 1 year after grazing (p>0.10) (Table 56). Spruce trees averaged 0.73 cm in diameter and were increasing in diameter at an average of 0.21 cm/yr. Average seedling height was 43.4 cm and leader length was 9.7 cm. Height:diameter ratio averaged 50.3 before grazing and 57.8 1 year later, indicating that both treated and untreated seedlings were becoming slightly more spindly.

Standardized spruce stem diameter distributions were similar in the treatment and the control prior to treatment, and the distributions became even more normal by the first-year assessment (Figure 63). Seedling height was more normally distributed than diameter prior to treatment, and the distribution changed little in the first year after treatment (Figure 64). Both the diameter and height distributions are consistent with the ANOVA results, which indicate that spruce did not respond to grazing treatments.

Competitive status Vegetation recovered quickly from grazing. One year after treatment, 61% of treated trees and 83% of control trees were overtopped and virtually none was free of vegetation (Figure 65). The competitive status of spruce actually declined following grazing because of the rapid recovery of the plant community.

TABLE 54 *Characteristics and history of the three replicate study sites where the ICH/ESSF Mixed Shrub Complex was grazed in hybrid spruce plantations*

	Site characteristics and history								Characteristics of target conifers at PROBE initiation					Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (years)	Origin[b]	Stock	Age[c] (years)	Height[d] (cm)	Abundance of major vegetation species cover (%) and height (cm)[d]	Total	Well spaced
Doug Creek PROBE 38 Clearwater District	ESSFwc2 07 (subhygric)	1530	W 50%	Podzol/ loam	Clearcut 1971 Burned 1972	23	22	22	P 1974 P 1993	PSB 313B 2+0	1	16 (4)	Thimbleberry cover: 20 (14) Thimbleberry height: 111 (21) Fireweed cover: 49 (21) Fireweed height: 129 (18) Lady fern cover: 37 (20) Lady fern height: 118 (20) All veg. cover: 99 (4) All veg. height: 130 (20)	1231	1064
Lower Saskum Plateau PROBE 71 Clearwater District	ICHmw3 01 (mesic)	1250	N 15%	Brunisol/ clay loam	Clearcut 1993 Burned 1993	4	4	2	P 1995	PSB 313B 1+0	2	34 (6)	Thimbleberry cover: 29 (15) Thimbleberry height: 54 (14) Raspberry cover: 34 (15) Raspberry height: 69 (14) Fireweed cover: 12 (10) Fireweed height: 59 (15) All veg. cover: 83 (10) All veg. height: 66 (17)	1192	953
Upper Saskum Plateau PROBE 72 Clearwater District	ICHmw3 01 (mesic)	1350	NW 30%	Brunisol	Clearcut 1993 Burned 1993	4	4	2	P 1995	PSB 313B 1+0	2	33 (6)	Thimbleberry cover: 22 (14) Thimbleberry height: 41 (15) Raspberry cover: 26 (12) Raspberry height: 63 (13) Fireweed cover: 16 (9) Fireweed height: 60 (13) All veg. cover: 85 (10) All veg. height: 61 (19)	1478	1089

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting

[b] Origin: P = planted; N = natural regeneration

[c] Age refers to the number of years since planting

[d] Values are means and one standard deviation (in parentheses)

TABLE 55 *A description of grazing treatments applied to the three replicate study sites to release hybrid spruce seedlings growing in the ICH/ESSF Mixed Shrub Complex*

Site	*Initial grazing* date	*Livestock* type	*Repeat* grazing
Doug Creek	August 1992 (site prep.) August 1993	Sheep	None
Lower Saskum Plateau	June 1997	Sheep	None
Upper Saskum Plateau	June 1997	Sheep	None

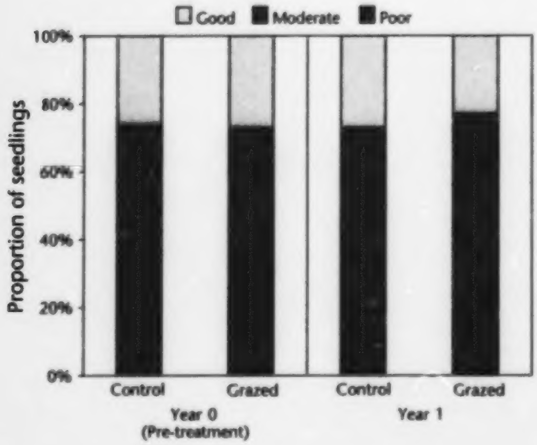


FIGURE 62 *Comparison of hybrid spruce vigour between the grazing treatment and control before and 1 year after treatment of the ICH/ESSF Mixed Shrub Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

TABLE 56 *Survival and growth responses of hybrid spruce seedlings to grazing in the ICH/ESSF Mixed Shrub Complex*

Response variable	Means Grazing	 Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	93	95	1.135	0.23
Stem diameter (cm)				
Pre-treatment	0.54	0.54	0.010	0.78
1 yr post-treatment	0.76	0.69	0.037	0.31
Diameter increment (cm)				
1 yr post-treatment	0.24	0.18	0.040	0.38
Height (cm)				
Pre-treatment	28.1	27.3	1.787	0.76
1 yr post-treatment	42.5	44.2	1.168	0.39
Leader length (cm)				
1 yr post-treatment	8.9	10.4	0.437	0.13
Height:diameter ratio				
Pre-treatment	51.2	49.4	3.267	0.74
1 yr post-treatment	54.0	61.5	3.790	0.29

The standard error of the mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

Plant community responses

Vegetation abundance Cover and height of total vegetation, shrubs, herbs, and thimbleberry recovered to control levels within 1 year of grazing ($p>0.10$) (Table 57), although there was variation among sites. Fireweed height and cover were significantly less in the grazing treatment (94.4 cm and 9.0%) than the control (116.7 cm and 23.9%) after 1 year ($p<0.10$) (Figure 66).

Richness and diversity of individual species and structural vegetation groups One year after sheep grazing, there were no significant differences between the treatment and control in richness or diversity of individual species ($p>0.10$) (Table 58) or structural vegetation groups ($p>0.10$) (Table 59). An average of 34 species were present prior to treatment and 35 species were present 1 year later.

In spite of grazing having no effects on richness or diversity, a number of individual species showed trends of changing abundance on at least two of the three study sites (Table 60). In the shrub layer, Sitka alder, goat's-beard (*Aruncus dioicus*), elderberry, and birch-leaved spirea (*Spiraea betulifolia*) all decreased in cover in the treatment relative to the control, while the presence of willow and red raspberry increased. Several herb species of varying stature were also affected. Those of medium to tall

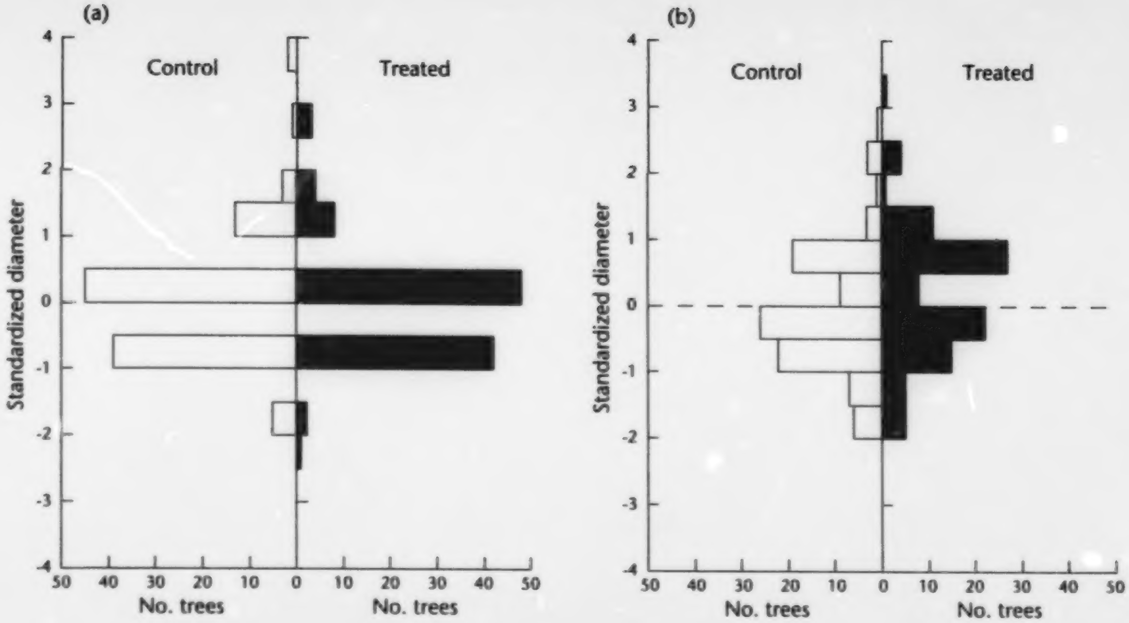


FIGURE 63 *Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH/ESSF* Mixed Shrub Complex *before and after sheep grazing. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment.*

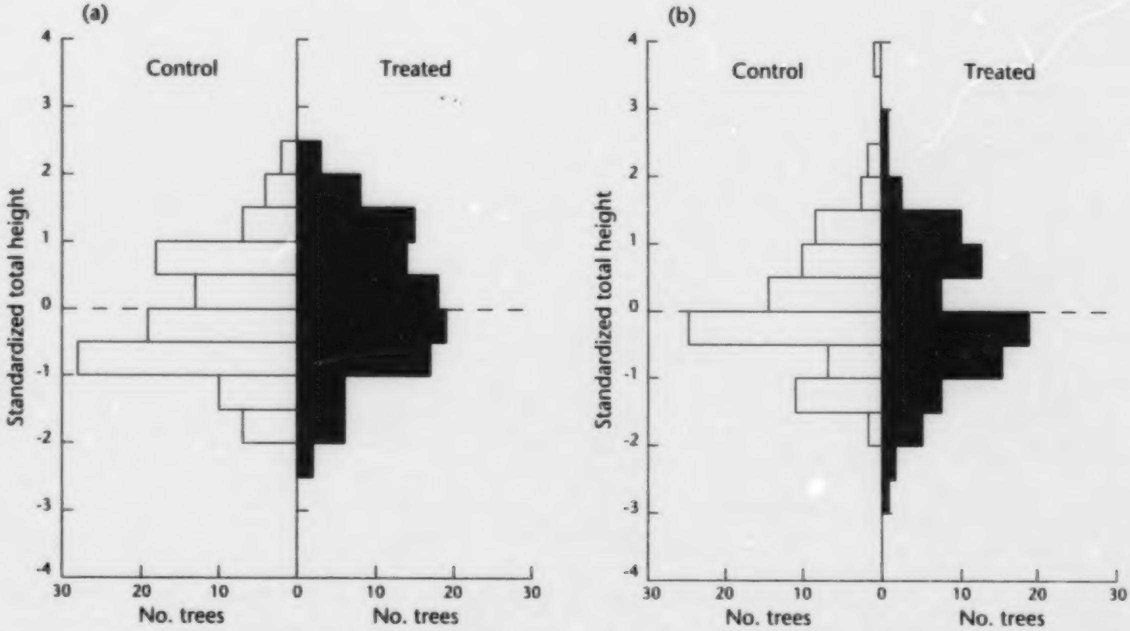


FIGURE 64 *Frequency of control and treated trees in standardized total height classes ($\mu = 0$; s.d. = 1; n = 3 for the control and treatment combined) for hybrid spruce in the ICH/ESSF* Mixed Shrub Complex *before and after sheep grazing. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment.*

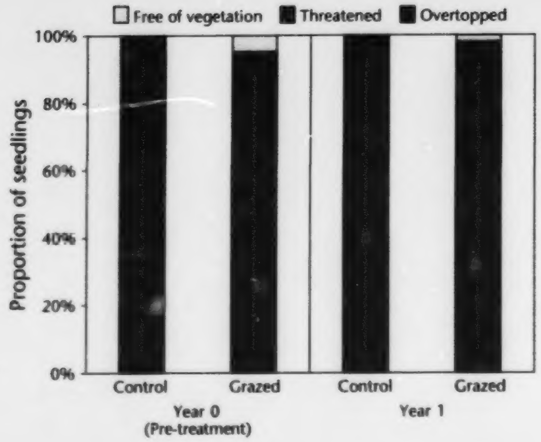


FIGURE 65 *Comparison of hybrid spruce competitive status between the grazing treatment and control before and 1 year after treatment of the ICH/ESSF* Mixed Shrub *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

stature that decreased in abundance were lady fern, fireweed, false Solomon's seal (*Smilacina racemosa*), clasping twistedstalk (*Streptopus amplexifolius*), veiny meadowrue (*Thalictrum venulosum*), and oxeye daisy (*Chrysanthemum leucanthemum*). The presence of three smaller herbs, Queen's cup (*Clintonia uniflora*), five-leaved bramble (*Rubus pedatus*), and rosy twistedstalk (*Streptopus roseus*), also decreased following grazing. Medium to tall herbs that increased in abundance following grazing were spiny wood fern (*Dryopteris expansa*), Sitka valerian (*Valeriana sitchensis*), Hooker's fairybells (*Disporum hookeri*), and grasses. Bunchberry (*Cornus canadensis*) was the only herb of small stature that increased in abundance following grazing. Species that appeared to be unaffected by grazing are listed in Table 60.

Competition Thresholds for Hybrid Spruce, Western Redcedar, and Douglas-fir

Competition thresholds were derived for stem diameter of hybrid spruce (Table 61), western

TABLE 57 *Cover and height of vegetation in the ICH/ESSF* Mixed Shrub *Complex before and after grazing in hybrid spruce plantations*

	Means		Standard	
Response variable	**Grazing**	**Control**	**error**	**p-value**
All vegetation				
Cover (%)				
Pre-treatment	89.4	88.8	4.051	0.92
1 yr post-treatment	79.5	93.2	9.619	0.31
Height (cm)				
Pre-treatment	83.8	87.6	3.759	0.55
1 yr post-treatment	74.1	96.9	7.959	0.18
Shrubs				
Cover (%)				
Pre-treatment	51.6	51.1	1.583	0.85
1 yr post-treatment	66.7	59.1	4.296	0.52
Height (cm)				
Pre-treatment	89.9	91.7	5.011	0.82
1 yr post-treatment	90.5	95.9	7.322	0.93
Herbs				
Cover (%)				
Pre-treatment	45.2	47.2	6.379	0.85
1 yr post-treatment	41.1	60.9	14.457	0.37
Height (cm)				
Pre-treatment	69.0	73.4	8.393	0.75
1 yr post-treatment	57.0	87.9	13.608	0.20
Thimbleberry				
Cover (%)				
Pre-treatment	24.4	22.8	2.068	0.63
1 yr post-treatment	19.3	22.0	4.244	0.76
Height (cm)				
Pre-treatment	70.6	66.5	2.089	0.30
1 yr post-treatment	51.9	68.0	5.468	0.24
Fireweed				
Cover (%)				
Pre-treatment	24.2	26.8	1.075	0.22
1 yr post-treatment	9.0	23.9	4.439	0.08*
Height (cm)				
Pre-treatment	82.4	82.4	2.838	1.00
1 yr post-treatment	94.4	116.7	2.822	0.01*

p-value denoted with "*" was significant at p ≤ 0.10 according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

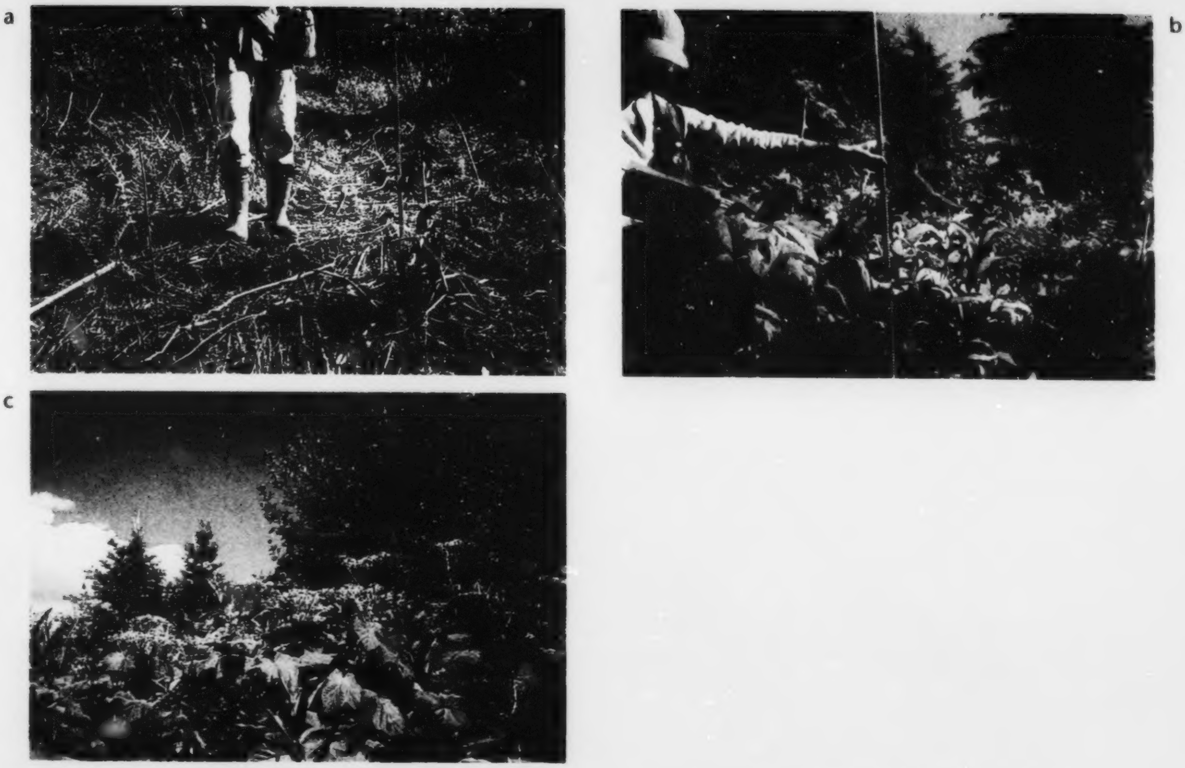


FIGURE 66 *Effects of sheep grazing on the* Mixed Shrub Complex *(a) 1 year and (b) 3 years following treatment. The control (c) is shown 3 years post-treatment for comparison. The plant community had recovered to control levels during the year after treatment.* Note: *Although the photo shows third-year responses, we report statistical results for only 1 year because not all replicate sites had been measured for 3 years. Photo credit: Silver Ring Forestry Ltd.*

TABLE 58 *Richness and diversity of vascular plant species in the ICH/ESSF* Mixed Shrub Complex *before and after grazing in hybrid spruce plantations*

	Means		Standard	
Response variable	**Grazing**	**Control**	**error**	**p-value**
Richness				
Pre-treatment	29.33	39.00	4.110	0.24
1 yr post-treatment	32.67	37.33	2.494	0.32
Shannon-Weaver Diversity Index				
Pre-treatment	2.40	2.32	0.035	0.27
1 yr post-treatment	2.42	2.35	0.027	0.21
Simpson's Diversity Index				
Pre-treatment	0.86	0.83	0.013	0.32
1 yr post-treatment	0.87	0.85	0.009	0.17

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 59 *Richness and diversity of structural vegetation groups in the ICH/ESSF* Mixed Shrub Complex *before and after grazing in hybrid spruce plantations*

	Means		Standard	
Response variable	**Grazing**	**Control**	**error**	**p-value**
Richness				
Pre-treatment	5.67	5.67	0.000	1.00
1 yr post-treatment	5.67	6.00	0.236	0.42
Shannon-Weaver Diversity Index				
Pre-treatment	1.00	1.06	0.056	0.51
1 yr post-treatment	1.09	1.06	0.041	0.62
Simpson's Diversity Index				
Pre-treatment	0.55	0.57	0.036	0.74
1 yr post-treatment	0.61	0.57	0.031	0.46

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 60 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following grazing of the ICH/ESSF* Mixed Shrub *Complex in hybrid spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Tall shrubs	*Salix* spp.	*Alnus viridis*	
Low shrubs	*Rubus idaeus*	*Aruncus dioicus* *Sambucus racemosa* *Spiraea betulifolia*	*Menziesia ferruginea* *Ribes lacustre*
Herbs	*Cornus canadensis* *Disporum hookeri* *Dryopteris expansa* *Valeriana sitchensis* Grasses	*Athyrium filix-femina* *Chrysanthemum leucanthemum* *Clintonia uniflora* *Epilobium angustifolium* *Rubus pedatus* *Smilacina racemosa* *Streptopus amplexifolius* *Streptopus roseus* *Thalictrum venulosum*	*Anaphalis margaritacea* *Cirsium arvense* *Equisetum arvense* *Galium triflorum* *Hieracium albiflorum* *Urtica dioica*

redcedar (Table 62), and Douglas-fir (Table 63) using all PROBE plantations dominated by the *Mixed Shrub* Complex. For hybrid spruce, the analysis included two sites that were manually brushed and three that were grazed with sheep ($n = 5$). For western redcedar and Douglas-fir, each analysis included one site that was manually brushed and one treated with glyphosate ($n = 2$ for western redcedar, $n = 2$ for Douglas-fir). All sites were located in the ICH zone, except for three that were located in the lower elevations of the ESSF zone. The age of seedlings (0–3 years old) varied little among sites. The thresholds were based on cover and height of all shrub species in the complex, where CRH = (shrub cover * modal shrub height)/seedling height.

The threshold for seedling diameter using shrub cover as the competition index averaged 74% and differed little among conifer tree species. The threshold varied little among sites, which may be associated with the narrow range in age of planted seedlings. The cover threshold was very high because seedling diameter varied widely across a broad range in shrub cover classes on all sites (maximum shrub cover was 100%) (e.g., Figures 67, 68, and 69). This variation is reflected in the non-significant linear regressions between stem diameter and shrub cover for all conifer species on all sites ($p>0.10$). The declines in seedling diameter above the cover threshold were gradual and small, suggesting that management of vegetation to threshold cover levels may not have predictable effects on seedling growth. Only 12% of all trees were growing in neighbourhoods above the threshold. There was a relatively even distribution of control and treated trees above and below the threshold. Most treated trees (86%) fell below the threshold. These results suggest that brushing treatments were successful at moving most trees below the threshold, but this was not difficult, given the high threshold level.

The CRH thresholds for diameter of Douglas-fir, hybrid spruce, and western redcedar averaged 48, 80, and 187, respectively. Seedling diameter usually declined sharply above the CRH thresholds (e.g. Figures 67, 68, and 69). On average, 43, 25, and 15% of Douglas-fir, hybrid spruce, and western redcedar, respectively, were growing in neighbourhoods above the thresholds, and these trees may therefore benefit from further selective brushing. There was a relatively even distribution of control and treated trees above and below the thresholds. Most treated trees (60–90%) fell below the thresholds, suggesting that brushing was successful at reducing shrub abundance below the CRH thresholds. The manual cutting treatment improved both mean diameter

TABLE 61 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting hybrid spruce stem diameter from the competition indices, shrub cover and CRH, in the* Mixed Shrub *Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from shrub cover[a]	Adjusted r^2 for linear regression predicting diameter from shrub cover[a]	p-value for linear regression predicting diameter from shrub cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
38	9	0	50	$y = 0.850 - 0.002\,x$	0.00	0.66	95	$y = 0.989 - 0.002\,x$	0.23	0.10		
60	68	1	75	$y = 0.523 - 0.001\,x$	0.12	0.11	110	$y = 0.508 - 0.000\,x$	0.21	0.00		
71	72	2	90	$y = 1.194 - 0.004\,x$	0.01	0.16	69	$y = 1.217 - 0.003\,x$	0.40	0.00		
72	69	2	95	$y = 0.573 - 0.004\,x$	0.08	0.11	105	$y = 1.033 - 0.002\,x$	0.09	0.01		
123	56	0	70	$y = 1.285 - 0.000\,x$	0.00	0.85	40	$y = 1.426 - 0.003\,x$	0.09	0.01	$y = 1.44\,e^{(-0.002*x)}$	0.12
mean (s.e.)			76 (8)				84 (13)					

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is shrub cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (shrub cover * shrub modal height)/spruce total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

TABLE 62 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting western redcedar stem diameter from the competition indices, shrub cover and CRH, in the* Mixed Shrub *Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from shrub cover[a]	Adjusted r^2 for linear regression predicting diameter from shrub cover[a]	p-value for linear regression predicting diameter from shrub cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
61	66	0	80	$y = 0.424 - 0.000\,x$	0.01	0.24	333	$y = 0.427 - 0.000\,x$	0.09	0.01	$y = 0.433\,e^{(-0.0005*x)}$	0.12
101	64	1	55	$y = 2.105 + 0.003\,x$	0.00	0.64	40	$y = 2.427 - 0.007\,x$	0.05	0.04		
mean (s.e.)			68 (13)				187 (147)					

[a] General form of linear equation is: $y = a + b\,x$, where y is western redcedar stem diameter, x is shrub cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is western redcedar stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (shrub cover * shrub modal height)/ western redcedar total height).

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is western redcedar stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

TABLE 63 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Douglas-fir stem diameter from the competition indices, shrub cover and CRH, in the* Mixed Shrub *Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from shrub cover[a]	Adjusted r^2 for linear regression predicting diameter from shrub cover[a]	p-value for linear regression predicting diameter from shrub cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
16	72	2	90	$y = 3.606 - 0.004\,x$	0.00	0.65	42	$y = 3.725 - 0.005\,x$	0.29	0.00		
103	67	3	65	$y = 4.095 - 0.011\,x$	0.01	0.22	54	$y = 4.179 - 0.012\,x$	0.26	0.00	$y = 4.702\,e^{(-0.0068*x)}$	0.32
mean (s.e.)			78 (18)				48 (9)					

[a] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is shrub cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (shrub cover * shrub modal height)/Douglas-fir total height).

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

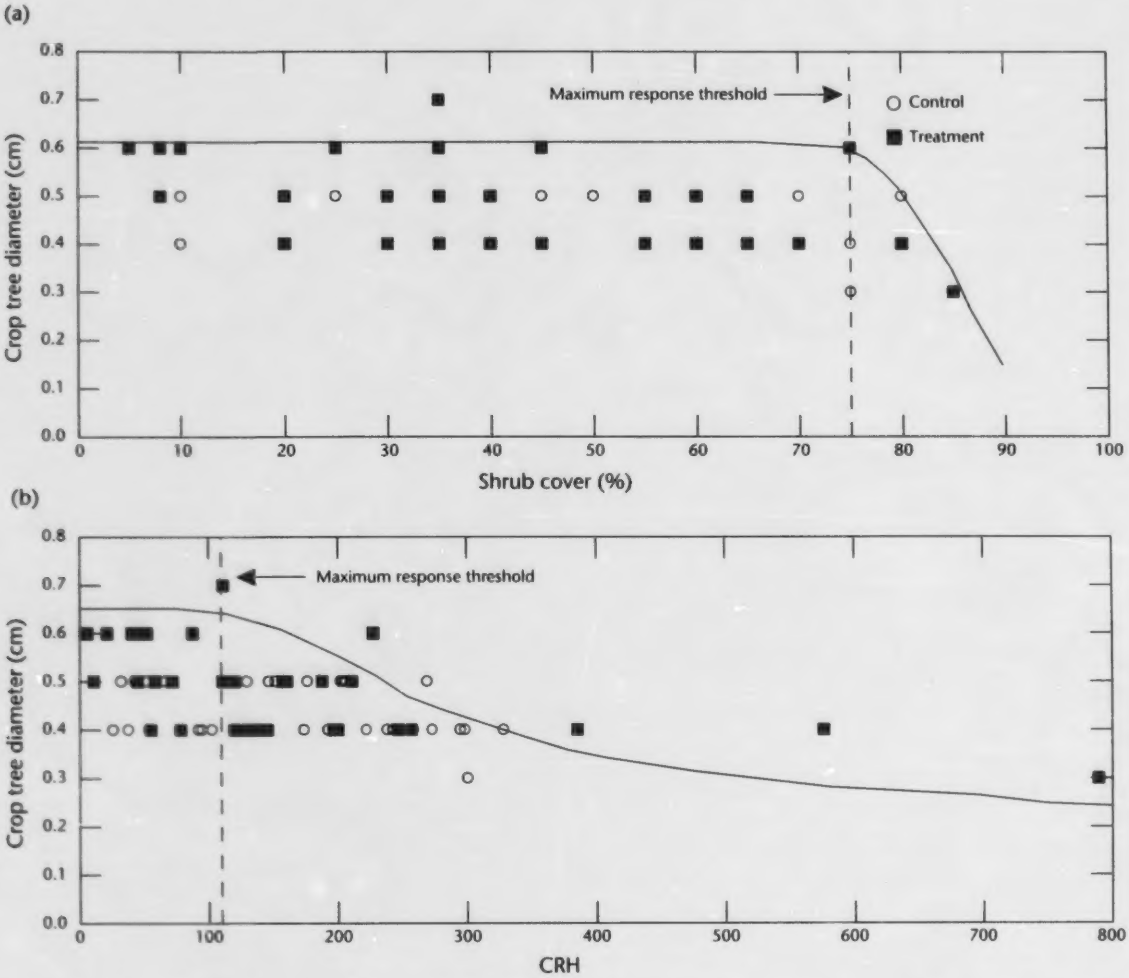


FIGURE 67 *Relationship between stem diameter of hybrid spruce growing amongst the ICH/ESSF* Mixed Shrub *Complex and (a) shrub cover or (b) CRH, where CRH = (shrub cover * shrub modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 60 (n = 68). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

growth ($p<0.10$) (Table 49) and the distribution of spruce diameters across mixed-shrub neighbourhoods (e.g., Figures 67, 68, and 69), indicating that manual reductions in shrub abundance below the thresholds was adequate to improve growing conditions in the plantations. However, sheep grazing had no effect on mean diameter or diameter distributions of hybrid spruce, and neither manual cutting nor glyphosate treatments appeared to improve diameter distributions of Douglas-fir or western redcedar. Of the treated trees that occurred in neighbourhoods below the CRH and cover thresholds, only 4% of spruce, 2% of Douglas-fir, and 14% of western redcedar achieved at least 80% of the maximum diameter growth measured on the sites.

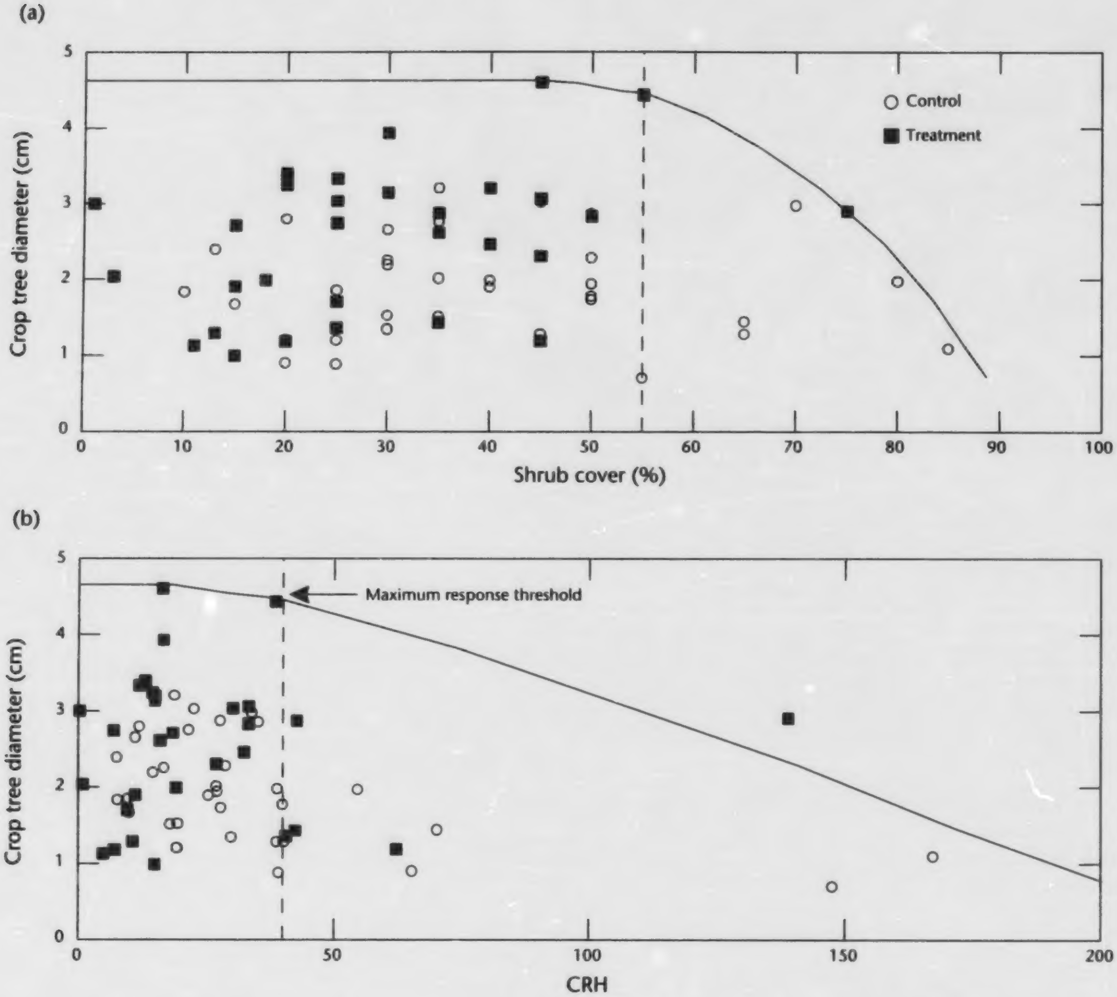


FIGURE 68 *Relationship between stem diameter of western redcedar growing amongst the ICH/ESSF* Mixed Shrub *Complex and (a) shrub cover or (b) CRH, where CRH = (shrub cover * shrub modal height)/cedar height. Data points include both treatment and control subplots for PROBE site 101 (n = 64). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover and CRH values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

Linear regressions of conifer diameter versus mixed shrub CRH were significant for all sites and tree species ($p<0.10$). Coefficients of determination were moderately high (adjusted r^2 0.05–0.40), but the slopes were relatively shallow (β_1 0 to -0.012) compared with other complexes. Fitting a negative exponential function to the diameter-CRH relationship slightly improved the adjusted r^2 values. The adjusted r^2 values and slopes of the relationships suggest that competition as measured by mixed-shrub CRH was of moderate importance but low intensity in these plantations.

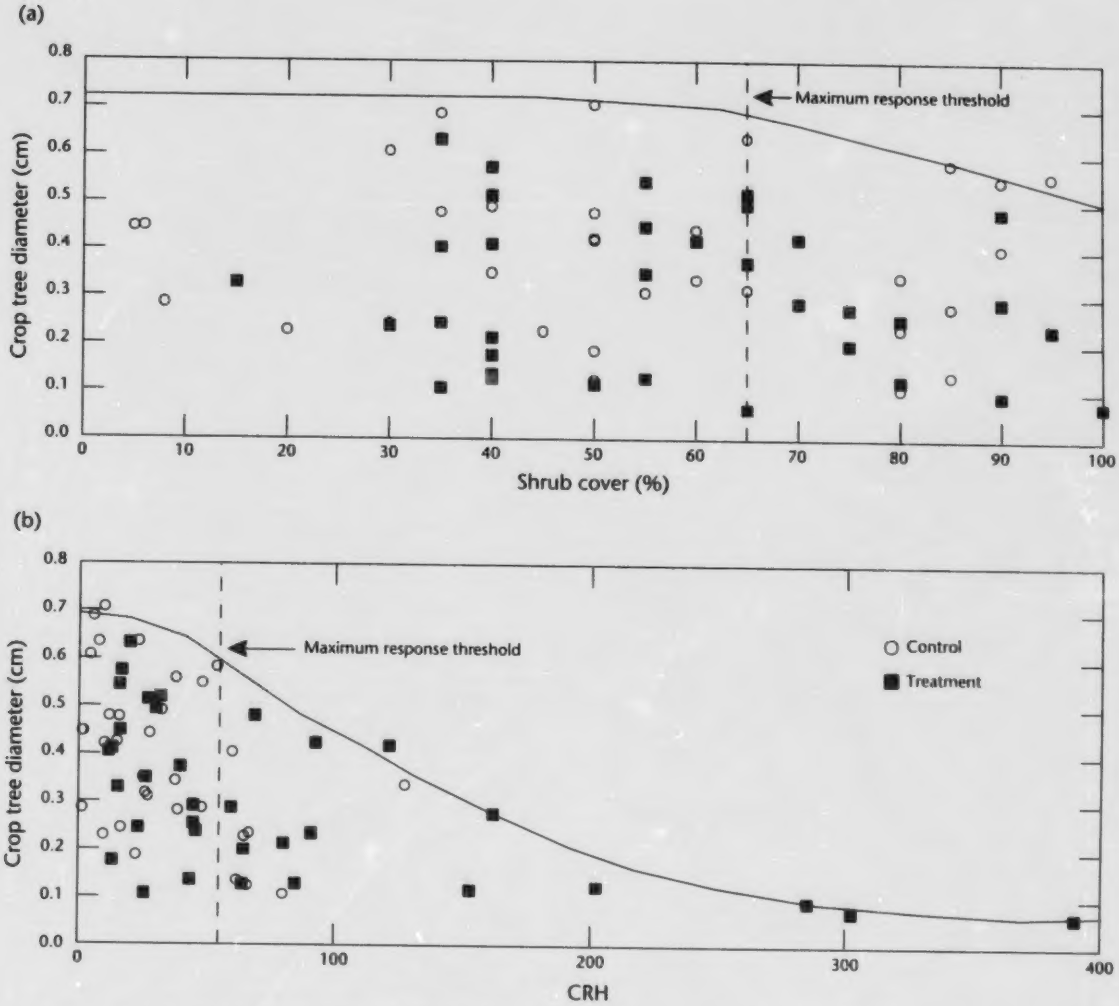


FIGURE 69 *Relationship between stem diameter of Douglas-fir growing amongst the ICH/ESSF* Mixed Shrub *Complex and (a) shrub cover or (b) CRH, where CRH = (shrub cover * shrub modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 103 (n = 67). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

The *Mixed Shrub* Complex develops on many productive sites in the southern interior wet belt following logging, and it may quickly overtop new plantations, even when they are established immediately after harvest. Brushing treatments are applied to this complex mainly to relieve the effects of competition for light, and to reduce damage from snow- and vegetation-press. Here we discuss third-year responses of hybrid spruce that were 0–3 years old at the time of manual cutting and first-year responses of hybrid spruce that were 1–2 years old at the time of grazing.

Manual Cutting

Conifer responses

Spruce seedling survival was excellent (average 97%) for 1 year after the *Mixed Shrub* Complex was manually brushed, but after 3 years, it had declined to an average of 75%, with no difference between the treatment and control. Almost all mortality was caused by competing vegetation, regardless of whether brushing was applied. Whitehead and Harper (1998) similarly found that brushing the ICH *Mixed Shrub* Complex had no effect on survival of planted spruce, but in that study, survival was somewhat higher (80–100%) in both the treatment and control. In contrast, Harper et al. (1998) found that 10 years after a single manual cutting treatment was applied to a shrub-dominated ICH community, Douglas-fir stocking was adequate in the treatment but not the control. However, that study included both natural and planted regeneration.

No mortality was attributed to cutting damage in our study; however, the *Mixed Shrub* Complex is often very dense, and there is considerable potential for treatment damage (Hart and Comeau 1992; Comeau et al. 2000a). In other studies, brushing the *Mixed Shrub* Complex with motorized brush saws resulted in 20–25% mortality after one cutting treatment (Holmsen and Whitehead 1988; Newsome 1988; Whitehead and Harper 1998). According to Boateng and Comeau (1997g), applying three repeated manual cutting treatments to the *Mixed Shrub* Complex can be expected to kill up to half the seedlings. Hockey sticks and other tools that bend rather than cut vegetation are sometimes used to reduce treatment damage.

Manual cutting allowed spruce stem diameter to increase by 23% within 3 years of treatment; however, the absolute size difference was relatively small (0.3 cm). Further monitoring is necessary to determine whether the difference between treatment and control is maintained, and whether it is likely to be biologically significant as trees mature. There were no improvements in seedling height or leader length during the 3-year assessment period, but seedlings were obviously becoming sturdier, and the tendency for stem diameter to respond in advance of height is well known (e.g., Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c). Other studies have shown that a single manual cutting treatment applied to shrub-herb vegetation communities had no effect on growth of spruce after 5–10 years (Whitehead and Harper 1998; Comeau et al. 2000a) or Douglas-fir after 10 years (Harper et al. 1998).

Conifer growth responses have generally been found to be greater following treatments that result in sustained rather than temporary (<1 year) reductions in abundance of the *Mixed Shrub* Complex. For example, Comeau et al. (2000a) showed that cutting a shrub-dominated community three times improved stem diameter of spruce by 54%, whereas one cutting had no effect. If cutting took place in summer rather than spring, height also improved. Similarly, in another study, seven repeated cutting treatments applied to the *Mixed Shrub* Complex over 3 consecutive years improved spruce stem diameter but not height (Comeau 1992a, 1992b). One of our unreplicated treatments on a reasonably similar site in the *Fern* Complex involved brushing eight times over 3 years, and spruce seedling survival, stem diameter, and height improved dramatically (Mather and Simard 1997f). We have not studied the effects of foliar glyphosate application, but Comeau et al. (2000a) found that a single glyphosate treatment resulted in approximately the same spruce growth response (46% improvement in stem diameter) as three manual brushing treatments. Other studies have also shown that spruce responds to glyphosate, but not to single manual cutting treatments (Whitehead 1989; Whitehead and Harper 1998). After carrying out critical-period analysis, Wagner et al. (1999) concluded that it was necessary to keep black spruce free of competing vegetation between years 1 and 3 after planting.

Not all studies agree with the need to sustain reductions in vegetation abundance. Jobidon and Charette (1997) found that black spruce growing among a fireweed and raspberry complex in Quebec responded to a single manual cutting treatment, and that the increases in stem diameter and height continued to be significant 10 years after treatment. By that time, seedlings were 13 years old, and those in the treatment had 24% (1.4 cm) larger stem diameter and were 12% (39 cm) taller than those in the control. Repeated brushing treatments in subsequent years did not increase seedling response in that study. Another study in British Columbia showed that a single manual cutting treatment applied to a shrub-dominated community improved stocking but not growth of Douglas-fir, and repeated treatments had no further effect (Harper et al. 1998).

Plant community response

In our study, vegetation was initially cut in July–August, and 1 year later, shrub cover and overall vegetation height were significantly lower in the treatment than the control. However, the actual magnitude of reductions was relatively small (10% less cover and 4 cm less height) and the differences had disappeared by year 3. The 3-year persistence of the slight reductions in abundance of the *Mixed Shrub* Complex following a single manual cutting treatment differs from the findings of others (Whitehead 1989; LePage et al. 1991; Hart and Comeau 1992; Comeau et al. 2000a), but are consistent with the slight increases in spruce stem diameter that we found. Other studies have shown that multiple cutting treatments (Comeau 1992a, 1992b; Comeau et al. 2000a) or a single glyphosate application (Whitehead 1989; Whitehead and Harper 1998; Comeau et al. 2000a) are required to significantly reduce abundance of the *Mixed Shrub* Complex for more than a single season.

Manual cutting had no effect on the richness of individual vascular plant species, but it decreased species diversity in year 3. The decrease in diversity was reflected in Simpson's Diversity Index but not the Shannon-Weaver Index, suggesting that the change was due to a decrease in the relative abundance of common species rather than the loss of rare species. This is supported by our findings that three common shrubs (thimbleberry, elderberry, and black huckleberry), four herbs (spiny wood fern, oak fern, small twistedstalk, and dandelion), and grasses tended to decrease in cover following manual cutting. Clement and Keeping (1996) report a similar lack of effect on species richness, while Haeussler (1999) notes that, in general, conventional forest management practices (including manual treatment) rarely affect diversity or richness of vascular plant communities.

Sheep Grazing

Conifer responses

One year after the *Mixed Shrub* Complex was grazed, survival of hybrid spruce averaged 94%, with no differences between the treatment and control. Vegetation caused most first-year mortality in the control, whereas sheep trampling caused mortality in the treatment. Survival following grazing was virtually the same as that 1 year after manual cutting, and given the similarity in seedling age and vegetation community between the two treatments, as well as observations at one of our sites, we expect there may be a decline in survival in both the grazing treatment and control as a result of vegetation competition by year 3. According to Newsome et al. (1995), trampling damage occurs only when flocks are poorly managed, and the problem occurred on only one of our study sites. Sheep may also browse conifer seedlings if they are more palatable than other vegetation. This problem can be avoided by applying grazing treatments after conifers have hardened off and by considering the relative palatability of target vegetation species (Newsome et al. 1995). Spruce are among the least palatable of conifers, and no browsing damage was recorded in our study.

Single sheep-grazing treatments had no effect on spruce size 1 year after treatment. This is consistent with results reported by Newsome et al. (1995), who showed that two or three grazing passes are necessary for a seedling growth response. Our *Fireweed* Complex results similarly showed that a single grazing pass did not improve spruce seedling growth (Section 4).

Plant community response

Although sheep-grazing had no effect on overall abundance of the *Mixed Shrub* Complex, both cover and height of fireweed were reduced in the first year after treatment. Fireweed is a preferred forage for sheep (Newsome et al. 1995), and its cover was reduced substantially (from 24 to 9%). Thimbleberry, the other target species in our study, was unaffected by grazing, which is also in keeping with Newsome et al. (1995), who report that it is grazed minimally or erratically. Grazing did not affect richness or diversity of individual species or structural vegetation groups in our study. We found the same result following grazing of the *Fireweed* Complex (Section 4).

Effects of the Community on Resource Availability

The *Mixed Shrub* Complex reduces conifer seedling performance mainly by competing for light, and by causing physical damage from vegetation- and snow-press. Physical damage is especially likely to occur after seedlings have become etiolated and spindly under a dense vegetation canopy. Brushing treatments are applied to ameliorate the competitive effects of this complex, and seedlings appear most able to respond when reductions in vegetation abundance are sustained (multiple cuttings or glyphosate) rather than short-lived (single manual cutting or grazing treatments) (e.g., Whitehead and Harper 1998; Comeau et al. 2000a). In addition to competing with conifer seedlings, the *Mixed Shrub* Complex may also benefit them by providing protection from frost damage and adding nutrient-rich organic matter to the forest floor.

In our study, manual cutting resulted in minor decreases in abundance of the *Mixed Shrub* Complex and small improvements in spruce stem diameter, but did not improve seedling survival, which averaged 75% by the time seedlings were 3–6 years old. We surmise that competition for light was the main cause of mortality because overall vegetation cover averaged 81% at the time of brushing, and some seedlings were overtopped by a thick canopy. The generally accepted light compensation point for spruce is 40–100 μmol m^{-2} s^{-1}, which occurs at 2–6% of full sunlight (Coates et al. 1994), and as little as 4–10% of full sunlight was found to reach the ground under a dense canopy of fireweed and thimbleberry (Comeau 1988). Comeau et al. (1993) showed that 63% of the variation in Engelmann spruce seedling growth could be explained by light transmittance.

The *Mixed Shrub* Complex appears to compete variably with conifer seedlings, possibly because it is composed of a wide variety of species with different growth habits, ground cover, and phenology. For instance, DeLong (1991) found that vegetation canopies dominated by fireweed substantially reduced the amount of light reaching seedlings by about mid-June, whereas those dominated by thimbleberry did not have the same competitive effect until about 3 weeks later. Species composition, and therefore light transmittance, is patchy in the *Mixed Shrub* Complex, and some seedlings may experience competition earlier in the growing season than others. Our competition threshold results also illustrate the variable competitive effects of this community.

In addition to restricting the amount of light reaching seedlings, vegetation canopies also restrict loss of heat from the soil during the night. Removal of the canopy could potentially increase the occurrence of summer frost damage; however, Stathers (1989) notes that low vegetation canopies are variable in their effect on frost injury. In some cases they benefit seedlings by restricting radiative heat loss, and in other cases they exacerbate the problem by restricting air mixing. On one of our sites, heavy frost damage was recorded in the first year after planting. It was more extensive in the treatment than the control, suggesting that the vegetation canopy had served to protect seedlings. LePage and Coates (1994) similarly report that a thimbleberry canopy protected spruce seedlings from frost damage. The *Mixed Shrub* Complex is common in both the ICH and ESSF zones, and at higher elevations, harsh climatic conditions likely affect its interaction with seedlings. Farnden (1994) stresses the importance of managing thermal regimes in the ESSF. Dense vegetation reduces soil and air temperatures (Spittlehouse and Stathers 1990), and manipulation of the vegetation canopy can improve thermal regime to some extent. However, low soil and air temperatures are unlikely to have been particularly relevant in our study, where the sites ranged in elevation from 500 to 1450 m.

The *Mixed Shrub* Complex tends to develop on sites with abundant moisture and nutrients, so competition for these resources is generally considered unimportant to conifer performance. Rather than reducing the availability of nutrients, the lush deciduous foliage shed by this community contributes annually to the forest floor. However, high nutrient levels may actually increase the severity of vegetation competition experienced by seedlings. For example, nutrient rather than light availability may govern the abundance of red raspberry in forest openings, and under high nitrogen conditions, red raspberry has been observed to increase in size at the expense of spruce seedlings (Lautenschlager 1999).

Competition Thresholds

The competition threshold for stem diameter of 0- to 3-year-old Douglas-fir, hybrid spruce, and western redcedar averaged 74% shrub cover, and did not vary among tree species. When CRH was used as the index, the thresholds were 48, 84, and 187 for Douglas-fir, hybrid spruce, and western redcedar, respectively. The cover thresholds were high, and above them seedling diameter declined gradually. In addition, linear regressions between spruce diameter and shrub cover were non-significant on all sites, reflecting the wide variability in seedling diameter across a broad range in cover classes. In contrast, spruce diameter declined sharply above the shrub CRH thresholds on most sites, and linear and non-linear regressions relating spruce diameter with CRH were highly significant with moderately high adjusted r^2 values.

These results suggest that cover alone was a poor measure of shrub competition, and that the relative stature of shrubs played an important role in their competitive influence on spruce seedlings. Different measures of competition have been used to infer competitive mechanisms in other studies (e.g., Weiner 1982; Newton and Jollife 1998), and the greater importance of our relative height (CRH) than cover index suggests that light competition may be more important than soil resource competition in these plant communities. Nevertheless, inferences about competitive mechanisms in the *Mixed Shrub* Complex should be used cautiously until controlled studies are conducted that more accurately identify mechanisms of interspecific interactions. Trends in cover and CRH thresholds in the *Mixed Shrub* Complex were similar to those observed in the *Fern* Complex, and in the plant communities studied by Comeau et al. (1993) (see Section 5 for a more detailed discussion).

Our data suggest that reducing mixed shrubs below the cover threshold may not improve seedling diameter growth predictably, whereas reductions below the CRH thresholds should relieve competitive constraints and improve conditions for seedling growth. Above the CRH threshold, interspecific competition appeared to be the most important factor limiting tree growth, setting the upper limit for seedling stem diameter. A moderate proportion of trees (15–43%, depending on tree species) were growing in environments above the CRH thresholds, suggesting that competition continued to constrain a considerable number of trees in the plantations, even after brushing. Most trees above the CRH thresholds were in the control, but many treated trees also fell into this category. This suggests that the brushing treatments were generally of low to moderate success at relieving competitive constraints. Below the thresholds, stem diameter was highly variable among both treated and control trees. Only 2% of Douglas-fir, 4% of spruce, and 14% of western redcedar that were brushed to levels below the CRH threshold achieved ≥80% of the maximum diameter measured on the sites, suggesting that factors other than fern competition (e.g., genetic, microenvironment, biotic) continued to constrain their growth.

Manual cutting reduced localized shrub abundance below the CRH threshold for 88% of treated spruce for the 1-year monitoring period. This corresponded with a small but significant improvement in mean spruce diameter, as well as improved diameter distributions compared with controls on all manually cut sites. Comeau et al. (2000a) found that either two or three annually repeated spring-summer manual cuttings or a single glyphosate application was necessary to reduce competition and release spruce seedlings. In contrast, single spring or summer cuttings were ineffective at reducing vegetation abundance for more than a single season and had no effect on 5-year seedling growth. Unfortunately, repeated manual cuttings have not yet been fully tested in our study.

Sheep grazing was less successful than manual cutting at reducing mixed shrubs below the CRH threshold; approximately half the treated and half the control spruce fell below the threshold 1 year after grazing. Mixed shrubs had fully recovered to control levels after 1 year, and there were no grazing effects on mean spruce diameter or diameter distributions compared with controls. As with single manual treatments, single grazing passes have been ineffective at releasing spruce seedlings in other studies (Newsome et al. 1995). Where plant communities are vigorous, Newsome (1996) found that at least two or three seasons of grazing were required to reduce vegetation abundance sufficiently to release seedlings.

The CRH thresholds for Douglas-fir (48), hybrid spruce (84), and western redcedar (187) suggest that western redcedar tolerates a much greater abundance of overtopping mixed shrubs than does either hybrid spruce or Douglas-fir. The species ranking of CRH thresholds generally agrees with traditional shade tolerance ranking, which follows the pattern of western redcedar>hybrid spruce>Douglas-fir (Krajina et al. 1982). In a recent study in the ICH zone, Coates and Burton (1999) found that western redcedar had greater height and diameter growth rates than hybrid spruce under low light (<30% full sunlight), but the reverse was true at high light (>70% full sunlight). Their results suggest that western redcedar should maintain faster growth rates than hybrid spruce under moderate–high mixed shrub abundance, but that hybrid spruce should out-grow western redcedar when shrubs are reduced below the CRH thresholds (or when >70% full sunlight is achieved).

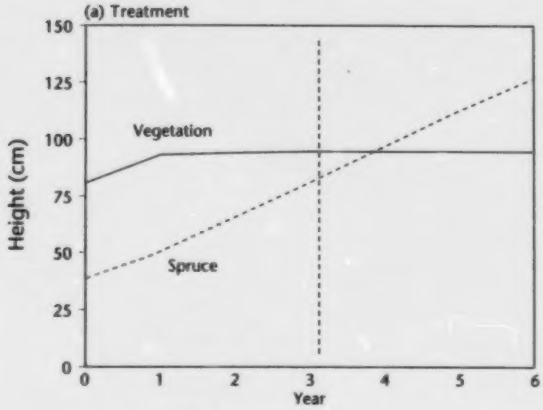
When mixed shrub densities are very high, brushing may be more critical for survival of hybrid spruce and Douglas-fir than for western redcedar. Kobe and Coates (1997) showed, for example, that at a radial growth rate of 0.5 mm yr^{-1} (a growth rate similar to that observed at low light), approximately 20% of hybrid spruce seedlings are expected to die compared with only 0.2% of western redcedar. In our study, survival of 3- to 6-year-old spruce was moderate (average 75%), regardless of whether or not manual cutting had been applied 3 years earlier, and nearly all mortality was attributed to vegetation competition. These results suggest that shrub densities reduced light below compensation levels for hybrid spruce. Higher survival was observed among Douglas-fir (98% after 5 years) and western redcedar (93% after 1 year) following single manual cutting or glyphosate treatments. Nevertheless, we estimate that approximately 20% of seedlings died immediately after planting and before brushing, and our observations of recent mortality suggest that vegetation competition may have been an important causal factor. Additionally, sites wetter than our mainly mesic sites may be at higher risk for competition-related mortality. This implies that brushing should occur promptly after planting, particularly on high-risk sites. The time span between logging or site preparation and planting should also be minimized so that seedlings are well established before mixed-shrub vegetation dominates the sites.

Effectiveness of Treatment at Meeting Management Objectives

The objectives of brushing the *Mixed Shrub* Complex are to improve seedling survival and growth and to ensure that stands meet free-growing requirements set out by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). For our ICH sites, the Code specifies target stocking of 1200 (minimum 700) well-spaced conifers/ha, and that within 9–15 years of establishment, spruce must be 1.0 m tall, and they must be 100% the height of neighbouring vegetation. For our ESSF sites, it also specifies target stocking of 1200 (minimum 700) well-spaced conifers/ha, and that within 12–20 years of establishment, spruce must be 0.8 m tall, and they must be 100% the height of neighbouring vegetation.

In our study, neither the manual cutting nor grazing treatments improved seedling survival, but we expect that stocking will be adequate unless there is considerable future mortality. Although the manual cutting treatment improved spruce stem diameter and height:diameter ratio, it did not significantly improve height. Height of the *Mixed Shrub* Complex is relatively static, however, and seedlings in the manual cutting treatment (on average) are expected to meet the minimum height for the ICH (1.0 m) and conifer:vegetation height ratio requirements (B.C. Ministry of Forests 2000) within 5 years of treatment, only 1 year ahead of control seedlings (Figure 70). As of the third-year assessment, when seedlings were 3–6 years old, they averaged 80.9 cm tall in the treatment, which was 85% of surrounding vegetation height, and 74.5 cm tall in the control, which was 75% of surrounding vegetation height. Spruce in the manual cutting treatment are therefore predicted to meet free-growing criteria when they are 5–8 years old and those in the control when they are 6–9 years old, on average. Both treated and control seedlings are predicted to reach free-growing by the earliest assessment age (on average), but silviculture survey information collected in future assessments will provide more information in this regard. In the first-year assessment after grazing, there were no treatment effects on either vegetation or seedlings. Although survival was good in that assessment, seedlings were too young (2–3 years old) to speculate about their eventual free-growing status.

(a) Treatment



(b) Control

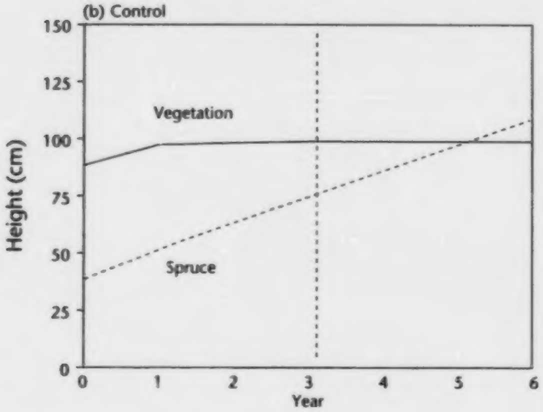


FIGURE 70 *Comparison of average spruce and vegetation height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH/ESSF* Mixed Shrub *Complex. Heights for years 0 through 3 are based on actual data (the value for year 2 was interpolated), and the heights for years 4 through 6 are projected on the basis of height growth rates in year 3. The vertical broken line indicates the most recent assessment year. Spruce are predicted to outgrow fireweed approximately 5 years after manual cutting and after 6 years in the control.*

We predict that, on average, brushing the *Mixed Shrub* Complex will not have been necessary for seedlings in our study to meet free-growing requirements (B.C. Ministry of Forests 2000). In contrast, other studies have shown that reducing vegetation abundance for 2–3 years facilitated the achievement of free-growing. Whitehead and Harper (1998) found that treating an ICH shrub-dominated community with glyphosate allowed a greater proportion of spruce to achieve free-growing 12 years after harvest than either a single manual cutting or no treatment. However, the density of free-growing seedlings in the glyphosate treatment was still too low to meet the minimum required by the Forest Practices Code. Where vegetation competition is so severe that early seedling survival is threatened, brushing treatments that provide a sustained (2–3 years) reduction in abundance are likely necessary. Guidelines for managing the *Mixed Shrub* Complex suggest that free-growing requirements are best met when sites are prepared and planted immediately after harvest and brushed as soon as necessary after planting (Boateng and Comeau 1997g). In our study, seedlings were an appropriate age to respond to brushing (0–3 years old), but treatment had little effect on their performance.

Our results for the *Mixed Shrub* Complex are similar to those for herb-dominated communities (i.e., *Fireweed* Complex, *Fern* Complex), in that single manual cutting or grazing treatments had only a short-lived effect on vegetation. These treatments appear unlikely to produce biologically significant long-term increases in seedling growth and are generally not contributing to the achievement of free-growing. However, further monitoring is required to ascertain the eventual effects on yield. The benefits of brushing these communities must be carefully assessed because brushing treatments are expensive, particularly when they are applied repeatedly. For instance, Comeau et al. (2000a) reported that three repeated manual cutting treatments improved spruce stem diameter by 54% at a cost of $2250/ha. Similar results were obtained by brushing with glyphosate, but at only one-third the cost for ground applications and one-seventh the cost for aerial applications in the southern interior. Chemical brushing is a less popular and accessible option in the southern interior, however, and aerial applications are particularly restricted because of public opposition to the practice. We suggest that brushing resources should be aimed at effectively treating those sites where vegetation competition is expected to reduce seedling survival below acceptable levels. Ensuring early survival is also expected to ensure adequate growth rates of those seedlings.

CONCLUSIONS

Single manual cutting and sheep-grazing treatments had little effect on abundance of the *Mixed Shrub* Complex in the ICH and ESSF zones. Neither brushing treatment significantly improved spruce survival, which was moderate (75%) 3 years after cutting and good (94%) 1 year after grazing on the sites we studied. Small increases in seedling stem diameter and decreases in height:diameter ratio were observed following manual cutting, but it is unknown whether they will persist in the longer term. Neither manual cutting nor sheep grazing significantly affected the richness or diversity of individual species or vegetation structural groups in this study.

Other studies suggest that improvements in seedling performance can more reliably be achieved when reductions in vegetation abundance are sustained for longer than 1 year. However, the ecological significance of the growth responses is unknown. Our results suggest that cover alone is a poor measure of mixed shrub competition, but that reducing vegetation abundance below CRH thresholds may improve spruce seedling performance. Variable responses to treatment are likely to be the norm.

Neither manual cutting nor grazing treatments are predicted to influence the achievement of free-growing (B.C. Ministry of Forests 2000) on our sites. Survival and conifer height growth were adequate in both the treatment and control for requirements to be met within the allowable time frame.

MANAGEMENT IMPLICATIONS

1. Single sheep grazing and manual cutting treatments did not substantially reduce abundance of the *Mixed Shrub* Complex. We found that manual cutting slightly reduced vegetation abundance for 1 year, which was associated with a small improvement in spruce growth. However, other studies have shown that two or three manual or grazing treatments, or a single glyphosate treatment, are required to reduce vegetation competition sufficiently to improve seedling performance.
2. Survival of hybrid spruce that were 0–3 years old at the time of manual cutting was moderate after 3 years, regardless of whether treatment was applied. Although survival was good 1 year after sheep grazing, vigour estimates suggest that there may be a decline by year 3. Our manual brushing and grazing treatments did not reduce vegetation abundance sufficiently to improve survival. Where seedling survival is at risk due to vegetation competition from the *Mixed Shrub* Complex, height of vegetation should be reduced below that of seedlings within 1–2 years of planting, and reductions in abundance should be maintained for at least 2–3 years.
3. Seedling stem diameter increased slightly and height:diameter ratio decreased as a result of manual cutting, which is in keeping with the minor and short-lived reductions in vegetation abundance.
4. Competition thresholds for seedling diameter averaged 48, 84, and 187 CRH for Douglas-fir, hybrid spruce, and western redcedar, respectively, and 74% mixed shrub cover for all three tree species. Reducing shrub abundance below the CRH thresholds should improve seedling diameter growth to a small degree, but reducing it below the cover threshold may not result in predictable seedling growth responses. Characteristics of the cover versus CRH thresholds suggest that the *Mixed Shrub* Complex affects spruce growth more by reducing light than by reducing soil resource availability.
5. Single manual cutting and sheep-grazing treatments had no effect on richness of individual species 3 years and 1 year after brushing, respectively, and only a minor effect on diversity. Rapid recovery of the plant community suggests that there will be no delayed treatment effects.
6. Sheep trampling caused considerable damage on one of our sites. Flocks must be carefully managed during brushing operations.
7. On our circum-mesic sites, brushing the *Mixed Shrub* Complex is not predicted to be necessary for seedlings to meet free-growing requirements. Brushing may be required on moister, richer sites where vegetation competition is sufficiently intense to threaten seedling survival. In such cases, multiple manual cuttings or a single glyphosate application is recommended.
8. An improved understanding of factors influencing the rate of development and intensity of competition in the *Mixed Shrub* Complex is required as a basis for improving the effectiveness of brushing prescriptions.

SECTION 7

Ericaceous Shrub and *Subalpine Herb* Complexes

ABSTRACT

We currently have fifth-year results regarding the effects of manual brushing treatments on ≤2-year-old Engelmann spruce seedlings and the *Ericaceous Shrub* Complex in the ESSF zone. The *Subalpine Herb* Complex is also discussed in this report because it is closely linked to the shrub community, but at present, we have insufficient replication of sites to carry out full analysis. Manual cutting had a relatively minor and short-lived effect on the *Ericaceous Shrub* Complex, but it was sufficient to improve survival of Engelmann spruce seedlings, and marginally improve growth. Height and cover of the shrub layer and overall vegetation were significantly reduced by 10 cm and 12%, respectively, for only 1 year. Herb abundance did not increase following removal of shrubs. Five years after brushing, 89% of treated seedlings survived compared to 71% of control seedlings ($p = 0.08$). Seedlings in the manual cutting treatment had significantly larger stem diameters than control seedlings in year 3, but not in year 5. Treated seedlings had longer leaders and lower height:diameter ratios than control seedlings in year 5.

For the *Ericaceous Shrub* Complex, competition thresholds for Engelmann spruce stem diameter averaged 52% shrub cover and 73 CRH, and manual brushing was moderately successful at reducing vegetation to below these values. For the *Subalpine Herb* Complex, no threshold was evident using herb cover as the competition index, but a CRH threshold of 184 was identified.

Manual cutting of the *Ericaceous Shrub* Complex increased species diversity (Shannon-Weaver Diversity Index) in comparison with the control, but had no effect on species richness. The cutting treatment is predicted to facilitate the achievement of free-growing status by helping to meet requirements for stocking, minimum height, and conifer:vegetation height ratio (B.C. Ministry of Forests 2000).

Description of the *Ericaceous Shrub* and *Subalpine Herb* Complexes

The *Ericaceous Shrub* and *Subalpine Herb* complexes are recognized as two separate communities that compete with conifers on high-elevation sites in southern interior British Columbia (Kimmins and Comeau 1990). However, there is considerable overlap in species between these two complexes. Factors such as harvesting methods, silvicultural treatments, and site characteristics play roles in determining whether a shrub- or herb-dominated community develops.

The *Ericaceous Shrub* Complex is most often dominated by white-flowered rhododendron (*Rhododendron albiflorum*), and can also include false azalea (*Menziesia ferruginea*), black huckleberry (*Vaccinium membranaceum*), and oval-leaved blueberry (*Vaccinium ovalifolium*) (Kimmins and Comeau 1990; Boateng and Comeau 1997a) (Figure 71). Although this community is composed mainly of shrubs, many of the herbs that dominate the *Subalpine Herb* Complex may be present in the understorey and in openings in the shrub canopy. The *Ericaceous Shrub* Complex occurs on dry to moist sites (Boateng and Comeau 1997a) within the wetter ESSF and upper ICH subzones (Kimmins and Comeau 1990).

The *Subalpine Herb* Complex occurs at elevations similar to those of the *Ericaceous Shrub* Complex; the two communities often occur in a mosaic of patches on the same site (Caza and Kimmins 1987). The *Subalpine Herb* Complex is dominated by a variety of herbs, including Sitka valerian (*Valeriana sitchensis*), fireweed (*Epilobium angustifolium*), Indian hellebore (*Veratrum viride*), woodrush (*Luzula* spp.), foamflower (*Tiarella unifoliata*), arnica (*Arnica* spp.), and twistedstalk (*Streptopus* spp.). It occurs predominantly in the ESSF zone, on somewhat moister (fresh to wet) sites than the shrub complex (Kimmins and Comeau 1990). Many species common to the *Subalpine Herb* Complex are also known to indicate rich site conditions (Klinka et al. 1989).

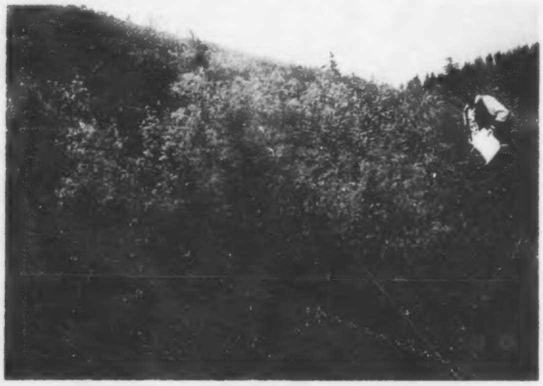


FIGURE 71 *The* Ericaceous Shrub *Complex prior to manual cutting at Howell Creek (Site 111) in the ESSFdk variant in the Cranbrook Forest District. Photo credit: JMJ Holdings Inc.*

Development of the *Ericaceous Shrub* and *Subalpine Herb* Complexes

The *Ericaceous Shrub* Complex is often present under the ESSF forest canopy, and although it does not develop or spread quickly, it may eventually become the dominant plant community following logging. This is particularly true on sites where, prior to harvest, it was well developed under the forest canopy or in openings. These conditions typically occur in very old, high-elevation ESSF forests, where the canopy tends to be open or with gaps. Ericaceous shrubs are negatively affected by disturbance to the forest floor, so the complex tends to develop on winter-logged sites where stems have been protected by the snowpack. In contrast, the *Subalpine Herb* Complex tends to develop following disturbance to the forest floor, such as that which occurs during summer-logging, mechanical site preparation, or medium- to high-impact broadcast burning (Caza and Kimmins 1987; Haeussler et al. 1990; Boateng and Comeau 1997a). Manual brushing of the *Ericaceous Shrub* Complex may also promote development of a vigorous *Subalpine Herb* Complex on sites where mainly rhizomatous herbs rather than mosses occur under the shrub layer (Boateng and Comeau 1997a).

The *Ericaceous Shrub* Complex tends to develop on somewhat drier and more nutrient-poor sites than the *Subalpine Herb* Complex. Rhododendron and false azalea grow best on mesic sites (Comeau et al. 1989), and oval-leaved blueberry and black huckleberry on mesic and drier sites (Haeussler et al. 1990). All four of these shrubs are associated with acidic soil conditions (pH<4.5), and occur on a range of nutrient regimes from poor to very rich in the British Columbia interior (Comeau et al. 1989; Klinka et al. 1989; Haeussler et al. 1990). In contrast, coastal British Columbia studies indicate that nearly all the herbs that occur in the *Subalpine Herb* Complex are associated with very moist, nutrient-rich site conditions (Klinka et al. 1989).

In southern interior British Columbia, the *Ericaceous Shrub* Complex can reach heights of 1–2 m, and rhododendron and false azalea, at least, are known to be long-lived (Angove and Bancroft 1983; Comeau et al. 1989). Rhododendron, false azalea, black huckleberry, and oval-leaved blueberry are all moderately shade tolerant to shade tolerant (Klinka et al. 1989), but display better growth under partial cover or open conditions than under a dense forest canopy (Haeussler et al. 1990). Shade tolerance of the herbs associated with the *Subalpine Herb* Complex is generally lower than that of the ericaceous shrubs, ranging from shade-intolerant to moderately shade tolerant (Klinka et al. 1989). Sitka valerian is the most aggressive member of this community, but all of the associated herbs respond quickly to increased light levels following harvest (Boateng and Comeau 1997a). Although the herbs in this complex are variable in height, most are likely to be taller than newly planted seedlings. Indian hellebore and fireweed commonly attain heights of 2 m and Sitka valerian a height of 1 m (Parish et al. 1996).

Shrubs associated with the *Ericaceous Shrub* Complex initially become established following seed dispersal by animals (black huckleberry and oval-leaved blueberry) or wind (rhododendron and false azalea) (Rogers 1974; Haeussler et al. 1990), and subsequently spread mainly by vegetative means. All *Vaccinium* species reproduce vegetatively via rhizomes, which, in the case of black huckleberry, are 8–30 cm below the soil surface (Minore 1975). False azalea sprouts from the root crown (Miller 1977), and may also spread by layering, which is an effective method of reproduction in ecosystems where a heavy snowpack pushes branches to the ground (Comeau et al. 1989). White-flowered rhododendron spreads via rhizomes, by sprouting from the root crown and adventitious buds, and by layering (Comeau et al. 1989; Haeussler et al. 1990). Less is known about individual species in the *Subalpine Herb* Complex, but all are rhizomatous (Parish et al. 1996), and presumably spread readily by vegetative means.

Interactions with Conifer Seedlings

The *Ericaceous Shrub* and *Subalpine Herb* complexes are both recognized as competitors to conifer seedlings in the southern interior of British Columbia (Kimmins and Comeau 1990). It is perceived that they are most likely to impede seedling establishment on cool, steep, north-facing slopes (Boateng and Comeau 1997a). Both communities create dense shade that can maintain soil temperatures below critical thresholds for water and nutrient uptake and reduce the availability of light for conifer seedlings (Coates 1987; Coates et al. 1991); however, recent work near Sicamous suggests that growth-limiting soil temperatures are not problematic on all ESSF sites where the *Ericaceous Shrub* Complex occurs (A. Vyse, pers. comm., 2000). In some cases, frost may damage seedlings that are newly planted in this community. Coates et al. (1991) found that spruce, but not pine, were damaged by frost in the first year after they were planted under a well-developed shrub canopy, but subsequent damage was minimal.

In addition to creating a harsh environment for seedling growth, springy ericaceous shrub stems may also cause physical damage to small seedlings (Boateng and Comeau 1997a). All of the species associated with this complex have well-developed root and rhizome systems. Though Coates et al. (1991) found no evidence of competition for soil resources on an ESSFwc2 study site, it may be a factor for seedlings growing on drier, nutrient-poor sites dominated by the *Ericaceous Shrub* Complex. There is also some evidence that white-flowered rhododendron may impede conifer performance through allelopathy (Del Moral and Cates 1971).

Importance to Wildlife and Range

Vaccinium species are the most important members of the *Ericaceous Shrub* Complex to wildlife. The berries are highly prized by black and grizzly bears, and are a key part of the diet for building up winter fat supplies (National Wildlife Federation 1987, cited by Haeussler et al. 1990). They are also eaten by small mammals and birds. Foliage and twigs of black huckleberry are browsed by bear, deer, rabbit, fox, and many other small mammals (Rogers 1974), and are of high importance as winter and spring browse for black-tailed deer (Singleton 1976, cited by Haeussler et al. 1990). Rhododendrons are generally considered unpalatable to ungulates (Nilsen 1986). False azalea is not an important wildlife species in British Columbia, but it may be used to a moderate extent by Columbia black-tailed deer and Roosevelt elk (Blower 1982).

Several herbs associated with the *Subalpine Herb* Complex are used by wildlife during the summer and fall. Sitka valerian is an important forage for Rocky mountain elk (Kufeld 1973), and the foliage is used moderately as summer food by bears, mule deer, elk, caribou, bighorn sheep, mountain goat, marmots, foxes, rabbits, and pikas (Haeussler et al. 1990). Fireweed is grazed to some extent by a variety of ungulates (Haeussler et al. 1990), but overall has low to moderate importance as a wildlife forage. Indian hellebore is grazed minimally by Rocky Mountain elk (Kufeld 1973), and is toxic to livestock (Parish et al. 1996).

None of the shrubs associated with the *Ericaceous Shrub* Complex is particularly useful to livestock. *Vaccinium* species may be grazed minimally by sheep, but false azalea is unpalatable and rhododendron is considered toxic (Newsome et al. 1995; Boateng and Comeau 1997a). Herb species associated with the *Subalpine Herb* Complex have variable palatability to livestock. Sitka valerian and fireweed are preferred forage species for sheep (Newsome 1996), and are also grazed to some extent by cattle (McLean 1979; Haeussler et al. 1990). Wood-rushes are of medium preference to cattle (McLean 1979).

Common Brushing Treatments in the *Ericaceous Shrub* and *Subalpine Herb* Complexes

A variety of brushing treatments is applied to the *Ericaceous Shrub* and *Subalpine Herb* complexes in southern interior British Columbia, including manual cutting, foliar glyphosate application, and sheep grazing (Tables 64 and 65). Site preparation prior to planting is recommended to prevent development and spread of the *Ericaceous Shrub* Complex. However, MSP, burning, and herbicide treatment all have the potential to shift vegetation from a shrub-dominated to a herb-dominated community (Boateng and Comeau 1997a), which will also require management.

TABLE 6.4 *Common brushing treatments applied to the Ericaceous Shrub Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Increase soil warming 2. Reduce light competition 3. Reduce snow- and vegetation-press 4. Reduce competition for soil resources	Unknown	1	1. Motorized brush saw	$538	1. Increased light may promote herb growth
Glyphosate (2.1 kg ai/ha)[b]	1. Increase soil warming 2. Reduce light competition 3. Reduce snow- and vegetation-press 4. Reduce competition for soil resources	Mid-July to mid-September[b]	1	1. Backpack sprayer 2. Fixed-wing plane or helicoptor (aerial)	$700	1. Cannot apply near waterways 2. *Vaccinium* spp. are somewhat resistant[c] 3. Shorter shrubs and herbs may be shielded from spray and spread following increase in light

[a] Based on average costs for the Kamloops and Nelson forest regions (B.C. Ministry of Forests 1999)
[b] Lloyd and Heineman (1994c)
[c] Conard and Emmingham (1983)

TABLE 65 *Common brushing treatments applied to the* Subalpine Herb *Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tools	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Increase soil warming 2. Reduce light competition 3. Reduce snow- and vegetation-press	Unknown	Multiple[d]	1. Motorized brush saw	$538	1. Vegetation is likely to recover quickly
Glyphosate (2.1 kg ai/ha)	1. Increase soil warming 2. Reduce light competition 3. Reduce snow- and vegetation-press	Early July to late August[b]	1	1. Backpack sprayer 2. Fixed wing plane or helicoptor (aerial)	$700	1. Cannot apply near waterways 2. Short treatment window
Grazing	1. Increase soil warming 2. Reduce light competition 3. Reduce snow- and vegetation-press	As soon as possible after conifers have hardened off[c]	2–3[c]	1. Sheep	$248	1. Potential for conifer damage if flocks are not carefully managed 2. Some common species are toxic or unpalatable to sheep[c]

[a] Based on average costs for the Kamloops and Nelson forest regions (B.C. Ministry of Forests 1999)

[b] Lloyd and Heineman (1994d)

[c] Newsome et al. (1995)

[d] Hart and Comeau (1992)

In this section we present results for manual cutting applied to the *Ericaceous Shrub* Complex. We currently have insufficient replication of sites in the *Subalpine Herb* Complex to present results.

Manual Cutting

Engelmann spruce in the ESSF zone

This section describes fifth-year responses of Engelmann spruce seedlings and the *Ericaceous Shrub* Complex to manual cutting in the ESSF zone (n = 4). Seedlings were from 0 (newly planted) to 2 years old at the time of treatment.

Description of study sites and treatments

Three of the four study sites are located in the Nelson Forest Region. The Corbin Pass site is 40 km northeast of Revelstoke in the Very Wet Cold ESSF subzone (ESSFvc) of the Revelstoke Forest District. The Ladybird Creek site is 9 km north of Castlegar in the Selkirk Wet Cold ESSF variant (ESSFwc4) of the Arrow Forest District. The Howell Creek site is 110 km east-southeast of Cranbrook in the Dry Cool ESSF subzone (ESSFdk) of the Cranbrook Forest District. One site is located in the Kamloops Forest Region; the West Gorge site is in the Salmon Arm District, 8 km north of Malakwa, in the Northern Monashee Wet Cold ESSF variant (ESSFwc2). Three of the sites are mesic and one is submesic, and they range in elevation from 1450 to 1800 m (Table 66). Three sites are in mid-slope position and one is lower slope. Site aspects are variable (north, east, southeast) but slopes are similar (25–45%). Soils are loam to silt loam textured Podzols and Brunisols.

PROBE was initiated on the four sites between 6 and 18 years after clearcut harvesting; the establishment delay ranged from 0 to 6 years (Table 66). Two of the sites received spot burn treatments 3 and 4 years after harvest, and one site was mechanically prepared 3 years after harvest. The fourth site received no site preparation. In all cases, there was a delay of at least 3 years between harvesting and the first planting attempt. Two of the sites had been planted more than once, and in all cases, the target conifers had been planted no more than 2 years prior to PROBE installation. Mortality of newly planted seedlings was high on the Corbin Creek site; fewer than 400 well-spaced stems/ha were counted at the time of PROBE installation. That site had been planted three times in the 18 years since harvest. At the time of treatment, total conifer stocking ranged from 2875 to 3761 stems/ha, of which 384–1200 stems/ha were well spaced.

Prior to manual brushing, shrubs were the dominant vegetation on all four sites, with cover values ranging from 46 to 82%. Average height of Engelmann spruce seedlings on the four sites ranged from 22 to 36 cm, whereas the shrub canopy ranged from 103 to 135 cm tall. On three of the sites, white-flowered rhododendron was the dominant shrub species, but on the Howell Creek site, which had the highest elevation and was north-facing, false azalea was dominant. Two sites also had uniform cover of black huckleberry and Utah honeysuckle (*Lonicera utahensis*).

Vegetation was cut in a variable radius (0.5–2.0 m) around target spruce seedlings on all four sites (Table 67). Cutting was carried out between mid-July and mid-September. Repeated treatments were carried out in the following year on two of the sites.

Conifer responses

Survival and vigour Three years after the *Ericaceous Shrub* Complex was manually cut, survival of 3- to 5-year-old Engelmann spruce seedlings (0–2 years old at the time of treatment) was significantly higher in the treatment (95%) than the control (81%) ($p = 0.03$) (Table 68, Figure 72). By year 5, when seedlings were 5–7 years old, survival had further decreased in both the treatment (89%) and the control (71%) ($p = 0.08$). In the fifth-year assessment, three-quarters of mortality in the control was attributed to competing vegetation, compared to less than half the mortality in the manual cutting treatment. Low mortality in both the treatment and the control were also attributed to wildlife, poor planting, and *Armillaria* root disease. Fifth-year silviculture survey data is unavailable for this complex.

Vigour of spruce seedlings declined slightly more in the control than in the treatment during the first 3 years after manual cutting (Figure 73). By year 5, however, many of the poor seedlings had died, and vigour of surviving seedlings was again similar in the treatment and control. Overall vigour declined slightly among both treatment and control

TABLE 66 *Characteristics and history of the four replicate study sites where the ESSF* Ericaceous Shrub *Complex was manually cut in Engelmann spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
West Gorge PROBE 20	ESSFwc2 01 (mesic)	1475	SE 35%	Podzol/ loam	Clearcut 1982 MSP 1985	10	7	0	P 1985 P 1991	PSB 415B 2+0	1	23 (6)	White rhododendron cover: 15 (13) White rhododendron height: 105 (32) Black huckleberry cover: 12 (9) Black huckleberry height: 81 (21) Utah honeysuckle cover: 7 (6) Utah honeysuckle height: 85 (34) Fireweed cover: 17 (15) Fireweed height: 110 (17) Valerian cover: 11 (10) Valerian height: 43 (16)	2875	1200
Corbin Pass PROBE 106	ESSFvc 01 (mesic)	1450	E 45%	Podzol/ silt loam	Clearcut 1974	18	n/a	0	P 1982 P 1986 P 1992	Unknown	0	36 (10)	White rhododendron cover: 15 (16) White rhododendron height: 77 (53) Black huckleberry cover: 16 (14) Black huckleberry height: 71 (25) Raspberry cover: 13 (10) Raspberry height: 55 (28) Fireweed cover: 23 (18) Fireweed height: 118 (14)	3761	384

TABLE 66 *Continued*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Ladybird Creek PROBE 110	ESSFwc4 01 (mesic)	1700	E 25%	Brunisol/ loam	Clearcut 1983 Spot burned 1986	9	6	6	P 1990	PSB 415	2	26 (5)	White rhododendron cover: 30 (14) White rhododendron height: 116 (21)	3506	1089
Howell Creek PROBE 111	ESSFdk 04 (submesic)	1800	N 40%	Unknown/ silt loam	Clearcut 1986 Spot burned 1990	6	2	1	P 1991	PSB 415B	1	22 (6)	False azalea cover: 66 (16) False azalea height: 138 (17)	3401	1192

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 67 *A description of manual cutting treatments applied to the four replicate study sites to release Engelmann spruce seedlings growing in the ESSF* Ericaceous Shrub *Complex*

Site	Initial treatment date	Treatment radius	Treatment tool	Repeat treatment
West Gorge	Late July, 1992	1.5–2.0 m	Brush saw	June 22–25, 1993
Corbin Pass	Late July, 1992	0.7 m	Machete	July 8, 1993
Ladybird Creek	September 15, 1992	0.7 m	Brush saw	None
Howell Creek	Mid-July 1992	0.5 m	Brush saw	None

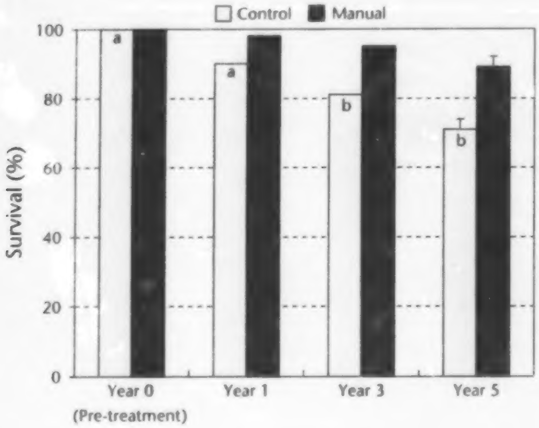


FIGURE 72 *Comparison of Engelmann spruce survival between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF* Ericaceous Shrub *Complex. Error bars are one standard error.*

seedlings during the 5 years that followed cutting, mainly because seedlings previously rated of good vigour had become moderate. At the start of the study, 35% of treatment seedlings and 40% of control seedlings were of good vigour. Five years later, only 16% and 10%, respectively, were good and the proportion of seedlings of moderate vigour had increased from approximately half to three-quarters.

Growth Engelmann spruce seedlings were 2 years old or less when pre-treatment measurements were carried out, and were of small stature. There was a minor pre-treatment difference in seedling root collar diameter (0.50 cm in the treatment versus 0.47 cm in the control, $p = 0.06$) (Table 68). Analysis of covariance was applied in subsequent years, and we found that diameter did not differ between the treatment and control 1, 3, and 5 years after cutting ($p>0.10$). Diameter increment was significantly greater among treated than control seedlings 3 years after cutting ($p = 0.06$), but this effect had disappeared by year 5 ($p>0.10$). Five years after treatment, seedlings averaged 55.1 cm tall, and there were no significant height differences between the treatment and control. However, seedlings had longer leaders in the treatment than the control in year five (7.1 versus 5.8 cm, $p = 0.09$) (Figure 74), as well as a lower height:diameter ratio (49.6 versus 54.2, $p = 0.05$).

Standardized diameter distributions were similar in the treatment and control prior to treatment (Figure 75), in spite of significant difference shown by ANOVA. After 5 years, the distribution continued to be approximately normal in the treatment, but frequencies increased in the smaller diameter classes in the control. This suggests that treated stems were becoming larger relative to those in the control as a result of brushing, but significant differences were not found with ANOVA. Future assessments will reveal whether the greater frequency of spruce stems in the -1 diameter class in the control (year 5) is the beginning of a trend among these slow-growing seedlings. The frequency of control spruce in smaller height classes also increased slightly during the 5-year assessment period (Figure 76), suggesting that treated seedlings were becoming taller relative to those in the control. However, ANOVA results did not show a significant height difference between control and treated spruce.

Competitive status Manual cutting of the *Ericaceous Shrub* Complex resulted in substantial improvements in the competitive status of Engelmann spruce seedlings, even though it did not completely free them from surrounding vegetation (Figure 77). Prior to treatment, virtually all seedlings were overtopped by surrounding vegetation; 1 year after cutting, none of the treated

TABLE 68 *Survival and growth responses of Engelmann spruce seedlings to manual cutting in the ESSF Ericaceous Shrub Complex*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	98	90	2.481	0.12
3 yr post-treatment	95	81	2.486	0.03*
5 yr post-treatment	89	71	5.002	0.08*
Stem diameter (cm)				
Pre-treatment	0.50	0.47	0.007	0.06*
1 yr post-treatment	0.58	0.56	0.017	0.67
3 yr post-treatment	0.84	0.75	0.015	0.36
5 yr post-treatment	1.16	1.00	0.028	0.35
Diameter increment (cm)				
1 yr post-treatment	0.09	0.11	0.014	0.26
3 yr post-treatment	0.13	0.11	0.004	0.06*
5 yr post-treatment	0.17	0.15	0.016	0.40
Height (cm)				
Pre-treatment	27.3	26.3	0.671	0.39
1 yr post-treatment	30.2	29.8	0.821	0.76
3 yr post-treatment	42.9	40.9	2.150	0.55
5 yr post-treatment	57.1	53.1	1.427	0.14
Leader length (cm)				
Pre-treatment	7.5	7.4	0.360	0.84
1 yr post-treatment	4.3	4.6	0.329	0.67
3 yr post-treatment	7.0	5.8	0.675	0.31
5 yr post-treatment	7.1	5.8	0.388	0.09*
Height:diameter ratio				
Pre-treatment	53.6	55.1	0.885	0.31
1 yr post-treatment	51.9	53.6	1.968	0.58
3 yr post-treatment	50.8	54.8	1.811	0.22
5 yr post-treatment	49.6	54.2	1.052	0.05*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 4$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

seedlings was overtopped, compared to 90% of control seedlings. By the third- and fifth-year assessments, approximately half of treated seedlings were again overtopped, compared to about 95% of control seedlings. The majority of treated seedlings that were not overtopped continued to be threatened by vegetation, however. By year 5, none of the control seedlings and only 7% of treated seedlings were free of surrounding vegetation.

Plant community responses

Abundance Manual cutting of the *Ericaceous Shrub* Complex significantly reduced height and cover of all vegetation and the shrub layer for 1 year (Table 69). The actual magnitude of these reductions was surprisingly small, probably because the treatment radius was small (0.5–0.7 m) on at least two of the sites, whereas vegetation was consistently assessed in a radius of 1.78 m, according to PROBE methodology. This resulted in the inclusion of both cut and uncut vegetation in height and cover estimates for the treatment. Figure 78 illustrates the slow recovery of ericaceous shrubs within the cutting radii.

Prior to manual cutting, shrubs averaged 58.2% cover and total vegetation 88.1%. Average height of the shrub layer was 116.8 cm. One year after manual cutting, shrub cover was reduced by 12% (60.0% in the control versus 48.2% in the treatment, p = 0.02) (Figure 79), and shrub height by 10 cm (96.7 cm in the control versus 86.5 cm in the treatment, p = 0.04) (Figure 80). Herb cover and height were unaffected by manual cutting during the entire 5-year monitoring period. Herb cover remained relatively constant from year to year (40–50%), but mean height varied from approximately 30 to 55 cm. Target species in the *Ericaceous Shrub* Complex varied from site to site, preventing analysis of height and cover of individual species.

Richness and diversity of individual species and structural vegetation groups In the *Ericaceous Shrub* Complex, there were no significant differences in species richness between the manual cutting treatment and the control during the 5-year monitoring period (p>0.10) (Table 70). An average of 27 species were present prior to treatment and 34 species 5 years later. Species diversity (Shannon-Weaver Diversity Index) was higher in the manual cutting treatment than in the control in the first and third years after treatment (p = 0.04 in year 1, p = 0.07 in year 3) (Table 70), but by year 5 the difference was no longer significant. When vegetation structural groups were considered, there were differences in diversity, but not in richness (Table 71). Diversity of groups was greater in the treatment than in the control in the third (p = 0.05 for H) and fifth years (p = 0.06 for H,

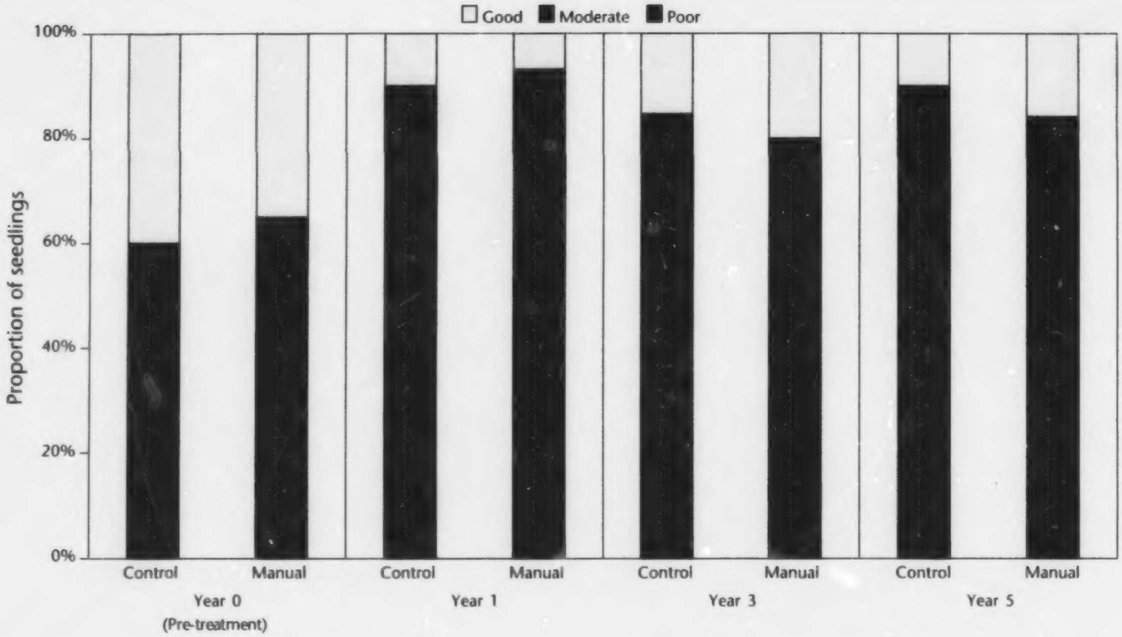


FIGURE 73 *Comparison of Engelmann spruce vigour between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF* Ericaceous Shrub *Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

p = 0.10 for SDI) after manual cutting. This difference was due to the ingrowth of tall broadleaves on the treated plot of one of the sites, and also to a reduction in the abundance of low shrubs following cutting, as indicated by the contrast in cover between control and treatment neighbourhoods shown in Figure 81. Vegetation cover was also more evenly distributed across the various vegetation groups following manual cutting, which helped increase diversity.

Manual cutting affected the abundance of several individual species in the *Ericaceous Shrub* Complex, but the changes varied somewhat from site to site. Ericaceous shrubs were the primary brushing targets, but only white-flowered rhododendron decreased in abundance across more than one site following manual cutting (Table 72). Its cover was reduced on three of the four sites, and it did not recover to pre-treatment levels within the 5-year monitoring period. Black twinberry (*Lonicera involucrata*) and Utah honeysuckle (*Lonicera utahensis*) were also present on all four study sites, but were not consistently affected by cutting. Two other shrub species decreased in abundance on more than one site following manual cutting. The presence of Sitka mountain-ash (*Sorbus sitchensis*) declined in the tall shrub layer (2–10 m) in the treated plots on three of the four study sites. Manual cutting also reduced the abundance of thimbleberry (*Rubus parviflorus*) on two of the four study sites.

Among herb species, only fireweed decreased in abundance as a result of manual cutting. On two of four sites, its cover was reduced for 1 year, after which it recovered to pre-treatment levels. On the other two sites, fireweed abundance was unaffected by the cutting treatment. Three other short herb species increased in cover following manual cutting. Pearly everlasting (*Anaphalis margaritacea*) cover increased in treated plots on two of the four sites, and sedges (*Carex* spp.) increased in cover in the treated plots of all four sites. On two of the four study sites, mountain sweet cicely (*Osmorhiza chilensis*) was absent from treated plots prior to cutting, but appeared in later assessments.

Other individual species increased or decreased

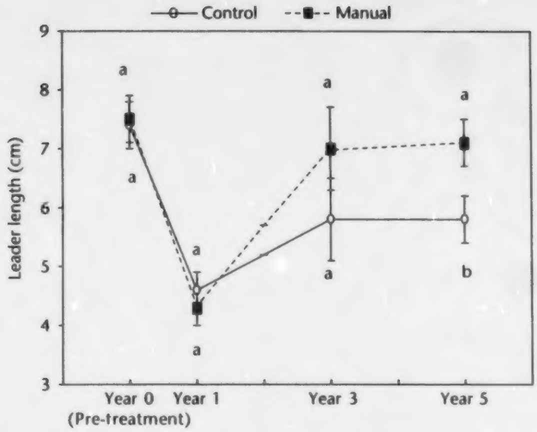


FIGURE 74 *Comparison of Engelmann spruce leader length between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ESSF Ericaceous Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 69 *Cover and height of vegetation in the ESSF Ericaceous Shrub Complex before and after manual cutting in Engelmann spruce plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
All vegetation				
Cover (%)				
Pre-treatment	87.8	88.4	3.567	0.92
1 yr post-treatment	80.4	90.1	2.448	0.07*
3 yr post-treatment	76.2	77.1	5.941	0.70
5 yr post-treatment	72.3	78.4	3.487	0.30
Height (cm)				
Pre-treatment	111.1	114.9	6.595	0.71
1 yr post-treatment	75.6	89.6	3.820	0.08*
3 yr post-treatment	90.4	100.1	11.306	0.39
5 yr post-treatment	87.1	104.0	6.184	0.15
Herbs				
Cover (%)				
Pre-treatment	40.6	48.9	2.939	0.14
1 yr post-treatment	50.5	51.5	3.254	0.85
3 yr post-treatment	41.8	43.8	2.748	0.35
5 yr post-treatment	44.1	43.9	3.431	0.97
Height (cm)				
Pre-treatment	42.8	53.0	4.185	0.18
1 yr post-treatment	28.6	43.9	7.557	0.25
3 yr post-treatment	39.1	48.5	8.584	0.59
5 yr post-treatment	30.5	34.9	3.794	0.47
Shrubs				
Cover (%)				
Pre-treatment	59.0	57.4	2.915	0.75
1 yr post-treatment	48.2	60.0	1.858	0.02*
3 yr post-treatment	48.1	51.0	7.482	0.56
5 yr post-treatment	49.8	58.4	3.297	0.16
Height (cm)				
Pre-treatment	118.7	114.9	2.343	0.34
1 yr post-treatment	86.5	96.7	2.013	0.04*
3 yr post-treatment	95.5	106.8	8.044	0.27
5 yr post-treatment	98.0	114.7	5.245	0.11

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 4. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

in cover, but did so on only one of the four sites. In general, cutting tended to favour increased cover of herbs, especially those of low stature. Sitka valerian, which is generally thought to increase in size and vigour following canopy removal (Haeussler et al. 1990), did not increase in abundance following cutting. Several berry-producing shrubs that are important to wildlife, such as black huckleberry, oval-leaf blueberry, red raspberry (*Rubus idaeus*), and elderberry (*Sambucus racemosa*) were present on these sites, but were, for the most part, unaffected by the cutting treatment. Thimbleberry alone was reduced in abundance by manual cutting.

Competition Thresholds

Competition thresholds were derived using all PROBE plantations in the *Ericaceous Shrub* and *Subalpine Herb* complexes regardless of the brushing treatment applied. In the *Ericaceous Shrub* Complex, the analysis included six manually brushed sites and two sites treated with glyphosate (n = 8) (Table 73). In the *Subalpine Herb* Complex, one site had been grazed with sheep ($n = 1$) (Table 74). In the *Ericaceous Shrub* Complex, the thresholds were based on cover and height of all shrubs, where CRH = (shrub cover * modal shrub height)/spruce height. In the *Subalpine Herb* Complex, the thresholds were based on cover and heights of all herbs in the complex, where CRH = (herb cover * modal herb height)/spruce height.

In the *Ericaceous Shrub* Complex, the shrub cover and CRH thresholds for Engelmann spruce diameter averaged 52% and 73, respectively (Table 73, Figure 81). The cover thresholds were not sharp on any of the sites, and above them the decline in spruce diameter was gradual. On some sites, cover thresholds were not much lower than the maximum neighbourhood covers, reflecting the wide variability in spruce diameters across most cover classes. In contrast, spruce diameter declined sharply above the CRH threshold on most sites.

A moderate proportion of trees (31–42%) were growing in neighbourhoods above the thresholds, and these trees may therefore benefit from further selective brushing. Most trees above the thresholds were control trees (59–62%), whereas most below the thresholds were treated trees (63%). Most treated trees (68–80%) and less than half of control trees fell below the thresholds, indicating that brushing was moderately successful at reducing ericaceous shrubs below the thresholds. However, mean spruce diameter did not differ significantly between the manual treatment and control ($p<0.10$) (Table 68). In addition, only 2% of treated spruce trees that were growing in neighbourhoods below the thresholds achieved ≥80% of the maximum diameter growth measured on the sites.

Linear regressions of spruce diameter versus ericaceous shrub cover were significant ($p<0.10$) for only three of eight sites. Of the significant regressions, coefficients of determination were low (adjusted r^2 0.10–0.23) and the slopes negative but shallow (β_1 -0.005 to -0.022). In contrast, linear regressions between CRH were significant ($p<0.10$) for six of eight sites, with moderately high adjusted r^2 values (0.19–0.37) and negative but shallow slopes (β_1 -0.001 to -0.005). Fitting a negative exponential function to the diameter-CRH relationship on one site improved the adjusted r^2 value from 0.37 to 0.43.

In the *Subalpine Herb* Complex, a threshold for Engelmann spruce diameter growth was not evident using herb cover as the competition index, and was 184 where CRH was used as the index (Table 74, Figure 82). Spruce diameter varied similarly across all herb cover classes, but declined above the CRH threshold. Approximately half the trees were growing in neighbourhoods above the CRH threshold, and these may benefit from further brushing. Two-thirds of treated trees fell below the thresholds, indicating that sheep grazing was moderately successful at reducing herbs to acceptable levels in the short-term. However, only 7% of grazed spruce trees growing below the CRH threshold achieved ≥80% of the maximum diameter measured on the sites. Diameter distributions were similar between the grazing treatment and control.

Linear regressions predicting spruce diameter were not significant where herb cover was used as the independent variable, but were significant where CRH was used. The diameter-CRH regression had a low adjusted r^2 value (0.17), and a negative, shallow slope (β_1 -0.001).

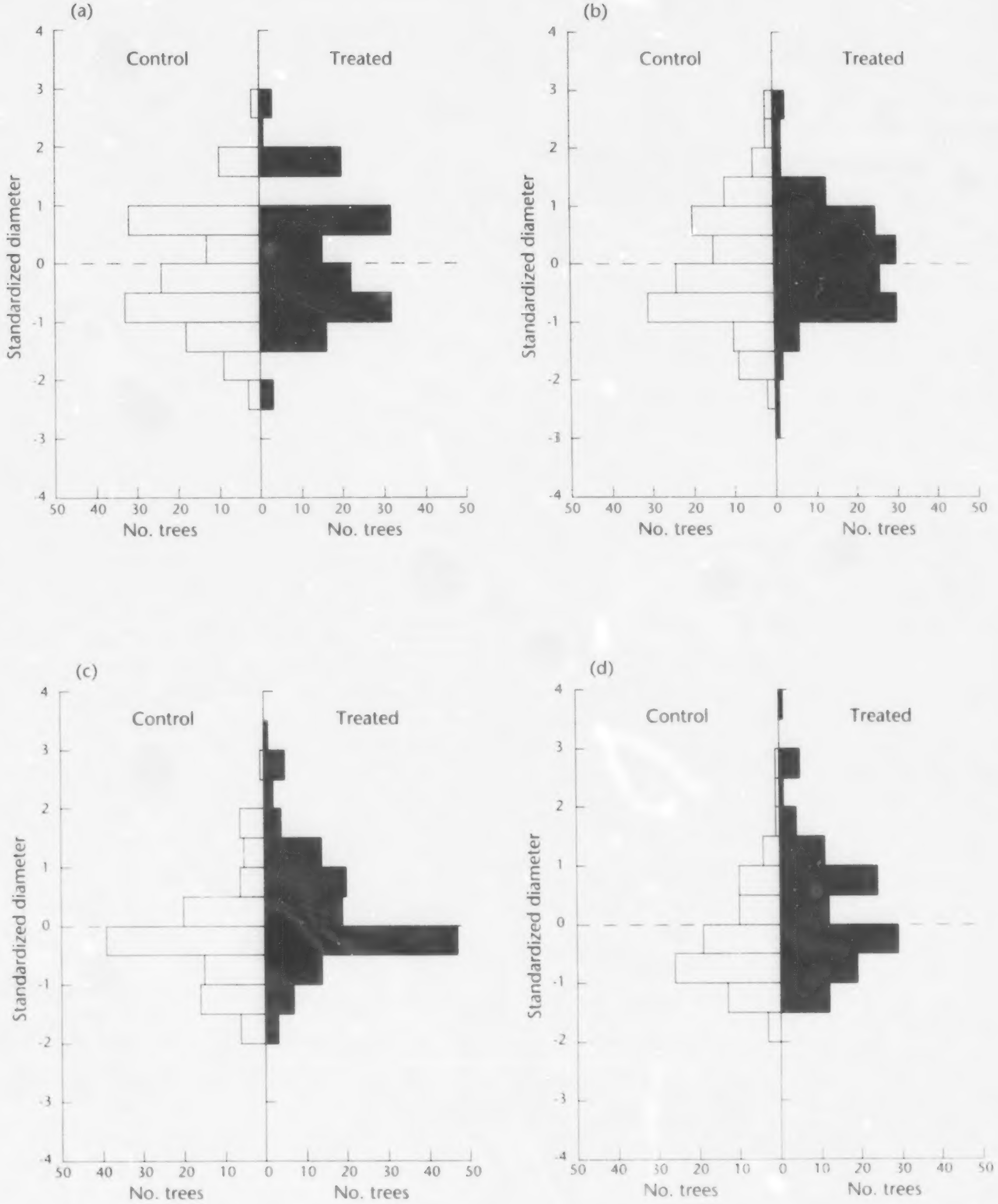


FIGURE 75 *Frequency of control and treated trees in standardized diameter classes ($\mu = 0$; s.d. = 1; $n = 4$ for the control and treatment combined) for Engelmann spruce in the ESSF* Ericaceous Shrub *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

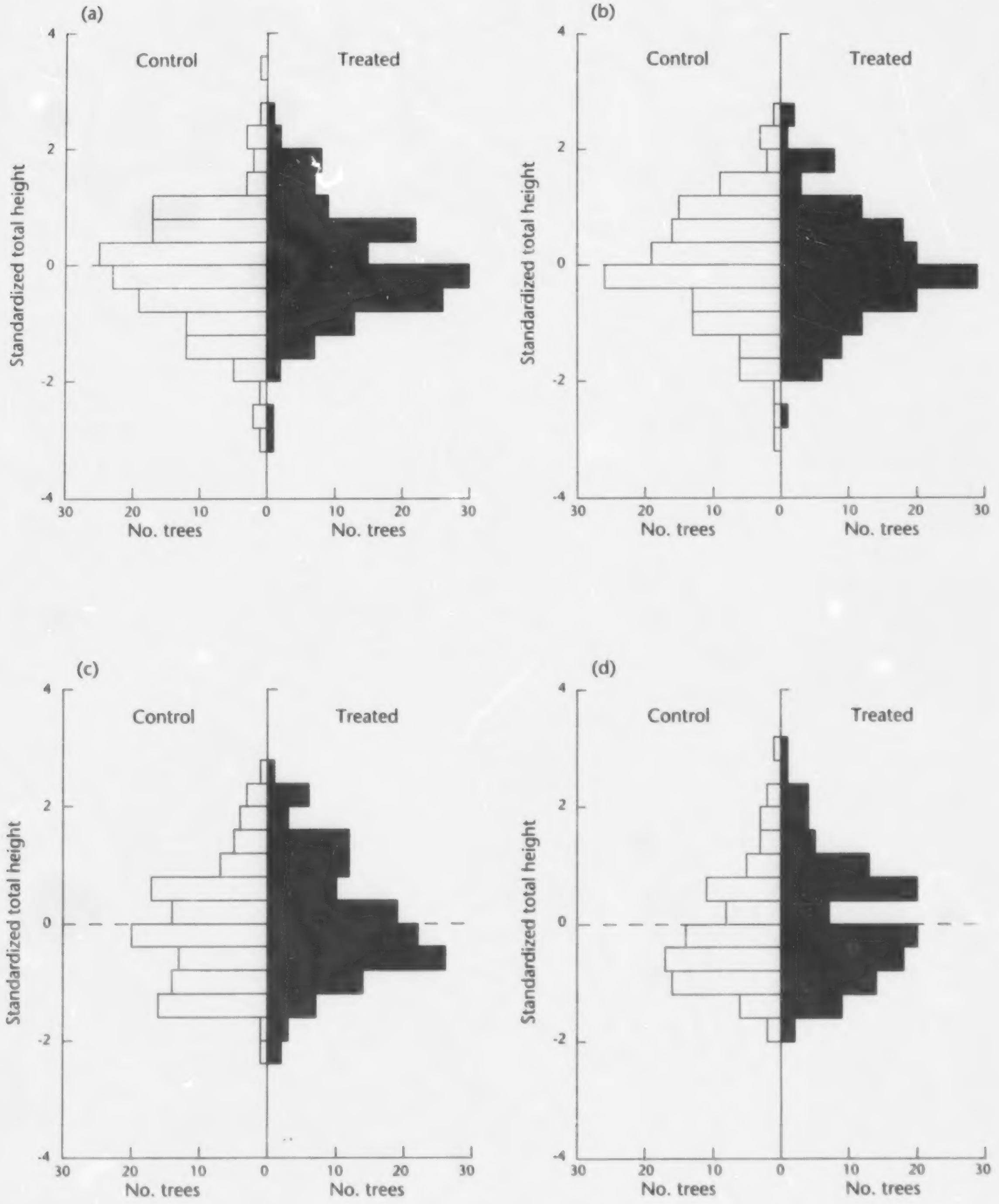


FIGURE 76 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 4 for the control and treatment combined) for Engelmann spruce in the ESSF* Ericaceous Shrub *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

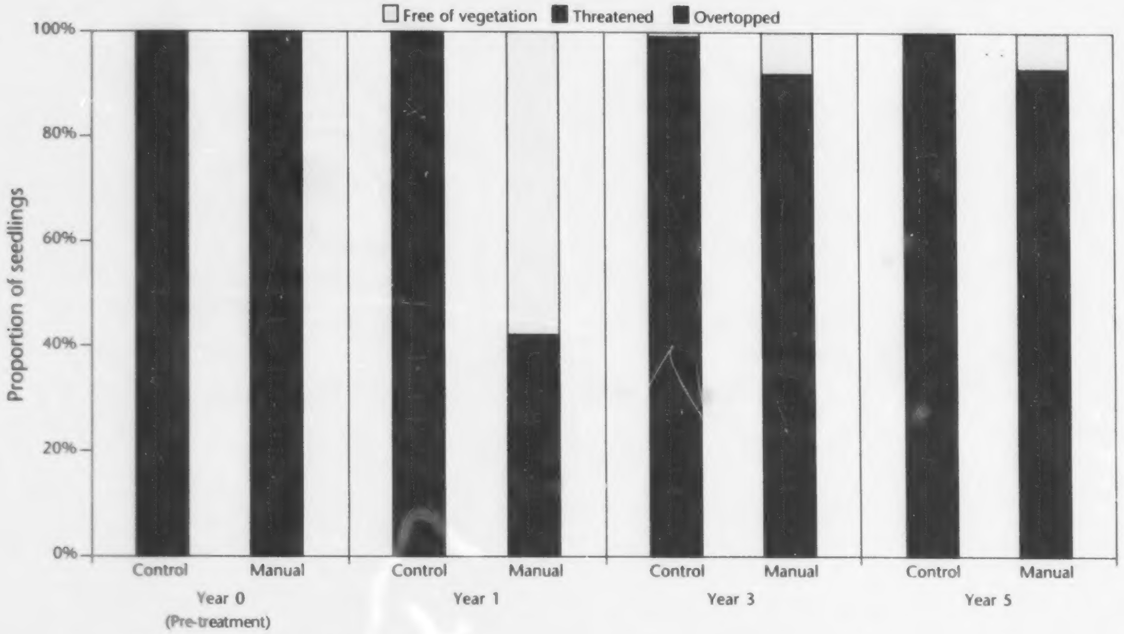


FIGURE 77 *Comparison of Engelmann spruce competitive status between the manual cutting treatment and control before, and 1, 3, and 5 years after treatment of the ESSF* Ericaceous Shrub *Complex.*

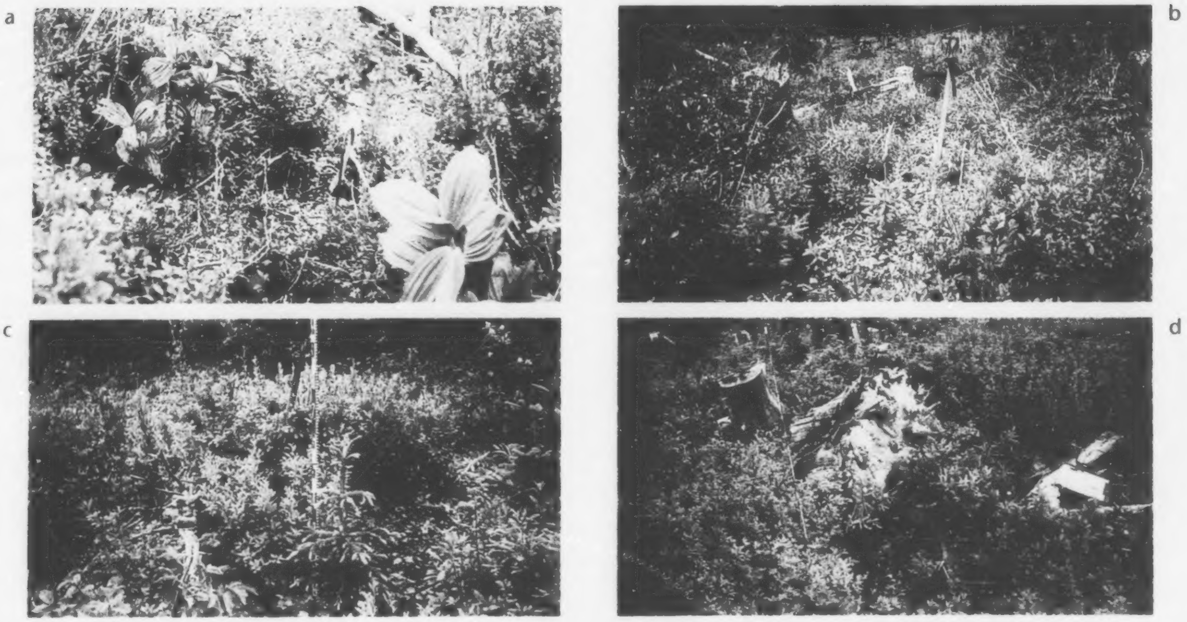


FIGURE 78 *Effects of tree-centred manual cutting on the* Ericaceous Shrub *Complex (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Ericaceous shrubs were slow to recover in the tree-centred plots following cutting. Photo credit: JMJ Holdings Inc.*

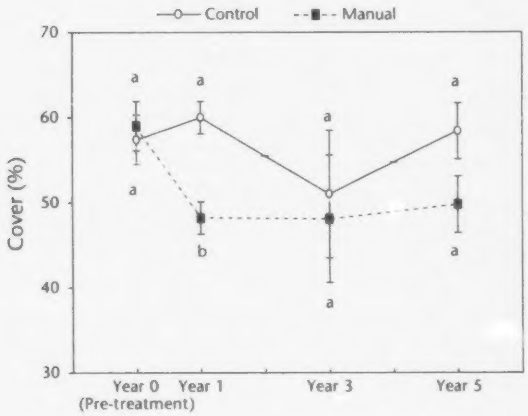


FIGURE 79 *Comparison of mean shrub cover between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF* Ericaceous Shrub Complex. *Error bars represent one standard error of the mean* ($\bar{y}$) *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

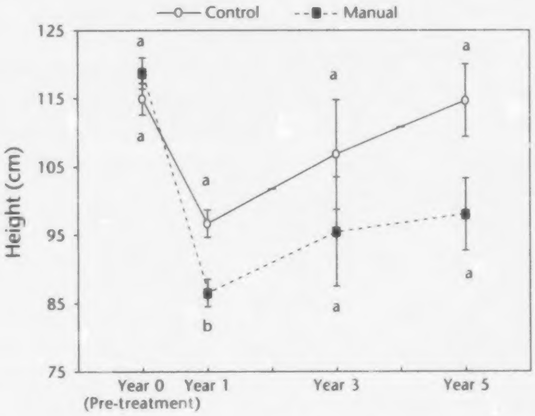


FIGURE 80 *Comparison of mean shrub height between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF* Ericaceous Shrub *Complex. Error bars represent one standard error of the mean* ($\bar{y}$) *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

TABLE 70 *Richness and diversity of vascular plant species in the ESSF Ericaceous Shrub Complex before and after manual cutting in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	28.00	26.50	1.926	0.62
1 yr post-treatment	29.00	29.50	1.021	0.75
3 yr post-treatment	33.25	30.25	1.915	0.35
5 yr post-treatment	35.00	33.00	2.255	0.57
Shannon-Weaver Diversity Index				
Pre-treatment	2.15	2.12	0.027	0.58
1 yr post-treatment	2.50	2.39	0.022	0.04*
3 yr post-treatment	2.29	2.09	0.049	0.07*
5 yr post-treatment	2.37	2.13	0.116	0.24
Simpson's Diversity Index				
Pre-treatment	0.80	0.82	0.007	0.27
1 yr post-treatment	0.88	0.86	0.007	0.14
3 yr post-treatment	0.84	0.79	0.020	0.24
5 yr post-treatment	0.82	0.74	0.047	0.30

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 4$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 71 *Richness and diversity of structural vegetation groups in the ESSF Ericaceous Shrub Complex before and after manual cutting in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	6.00	6.00	0.289	1.00
1 yr post-treatment	6.00	6.00	0.289	1.00
3 yr post-treatment	6.00	6.00	0.289	1.00
5 yr post-treatment	6.00	5.75	0.177	0.39
Shannon-Weaver Diversity Index				
Pre-treatment	1.16	1.13	0.061	0.69
1 yr post-treatment	1.28	1.20	0.047	0.31
3 yr post-treatment	1.29	1.06	0.049	0.05*
5 yr post-treatment	1.30	1.07	0.051	0.06*
Simpson's Diversity Index				
Pre-treatment	0.61	0.59	0.031	0.72
1 yr post-treatment	0.66	0.63	0.017	0.34
3 yr post-treatment	0.66	0.55	0.034	0.11
5 yr post-treatment	0.65	0.55	0.021	0.10*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 4$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 72 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ESSF* Ericaceous Shrub *Complex in Engelmann spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	**Decreasing cover**	**No change in cover**
Tall shrubs		*Sorbus sitchensis*	
Low shrubs		*Rhododendron albiflorum* *Rubus parviflorus*	*Lonicera involucrata* *Lonicera utahensis* *Pachistima myrsinites* *Ribes lacustre* *Rubus idaeus* *Salix* spp. *Sambucus racemosa* *Vaccinium membranaceum*
Herbs	*Anaphalis margaritacea* *Carex* spp. *Osmorhiza chilensis*	*Epilobium angustifolium*	*Grass* spp. *Luzula parviflorus* *Orthilia secunda* *Rubus pedatus* *Streptopus amplexifolius* *Streptopus roseus* *Thalictrum occidentale* *Tiarella trifoliata* *Valeriana sitchensis* *Veratrum viride* *Viola* spp.

TABLE 73 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Engelmann spruce stem diameter from the competition indices, shrub cover and CRH, in the Ericaceous Shrub Complex in the ESSF zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from shrub cover[a]	Adjusted r^2 for linear regression predicting diameter from shrub cover[a]	p-value for linear regression predicting diameter from shrub cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
20	32	1	60	$y = 1.299 - 0.004\,x$	0.00	0.42	110	$y = 1.366 - 0.002\,x$	0.24	0.00		
43	62	1	75	$y = 1.486 - 0.005\,x$	0.10	0.01	130	$y = 1.594 - 0.003\,x$	0.36	0.00		
106	50	0	70	$y = 1.782 - 0.003\,x$	0.00	0.50	53	$y = 2.038 - 0.005\,x$	0.27	0.00		
110	67	2	55	$y = 0.859 - 0.000\,x$	0.00	0.88	100	$y = 1.124 - 0.002\,x$	0.19	0.00		
111	57	1	55	$y = 1.167 - 0.006\,x$	0.18	0.00	35	$y = 1.049 - 0.002\,x$	0.37	0.00	$y = 1.150\,e^{(0.002 * x)}$	0.43
120	68	4	10	$y = 1.130 - 0.001\,x$	0.00	0.50	40	$y = 1.155 - 0.001\,x$	0.02	0.12		
128	72	9	60	$y = 1.623 - 0.005\,x$	0.01	0.19	47	$y = 1.967 - 0.003\,x$	0.02	0.11		
129	70	6	35	$y = 3.054 - 0.022\,x$	0.23	0.00	65	$y = 2.454 - 0.004\,x$	0.20	0.00		
mean (s.e.)			52 (7)				73 (13)					

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is shrub cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (shrub cover * shrub modal height)/spruce total height.

[c] General form of non-linear equation is $y = a\,e^{(b * x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

TABLE 74 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting hybrid spruce stem diameter from the competition indices, herb cover and CRH, in the Subalpine Herb Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from herb cover[a]	Adjusted r^2 for linear regression predicting diameter from herb cover[a]	p-value for linear regression predicting diameter from herb cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]
14	53	0	None	$y = 0.733 - 0.000\,x$	0.00	0.86	184	$y = 0.913 - 0.001\,x$	0.17	0.00

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is herb cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (herb cover * herb modal height)/spruce total height.

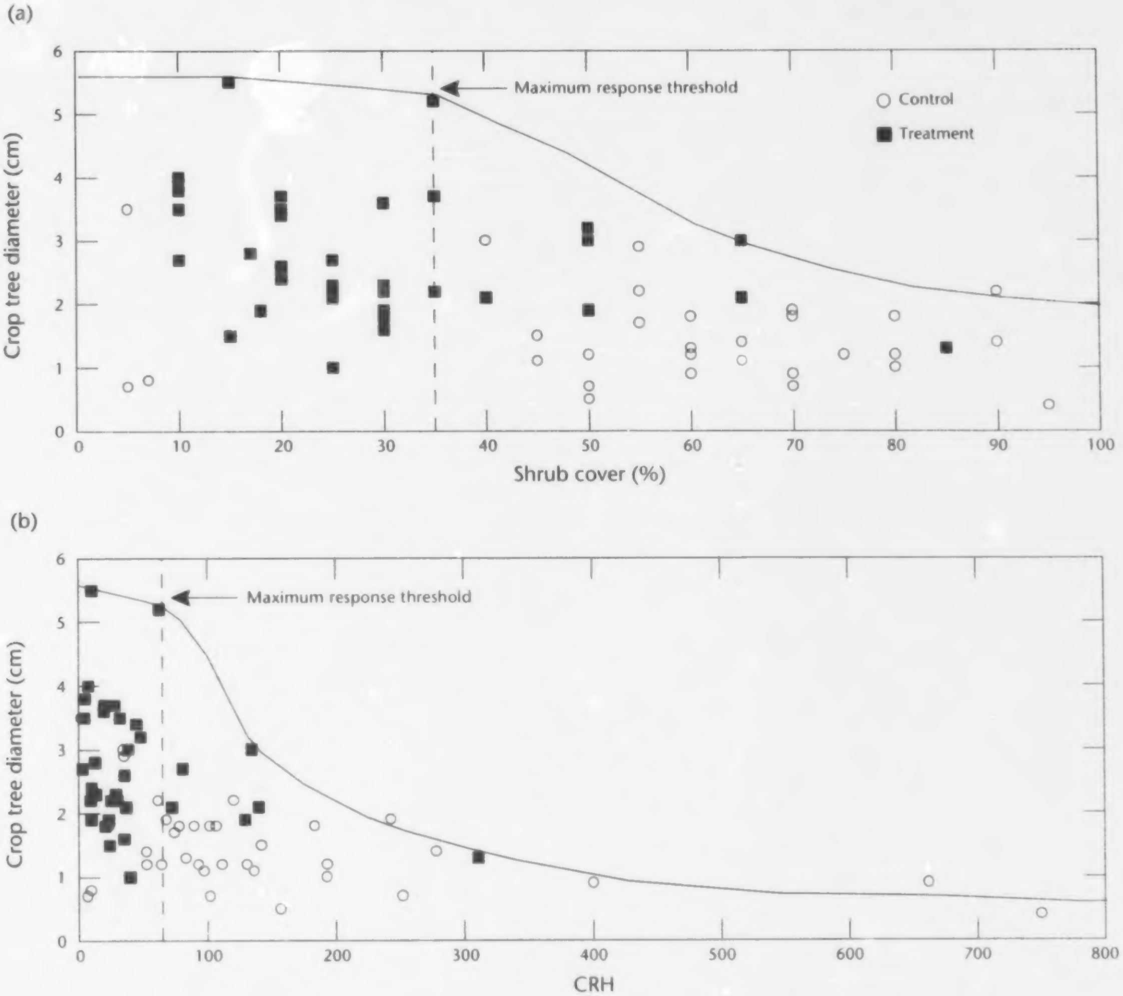


FIGURE 81 *Relationship between stem diameter of Engelmann spruce growing amongst the* Ericaceous Shrub Complex *and (a) shrub cover or (b) CRH, where CRH = (shrub cover * shrub modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 129 (n = 70). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

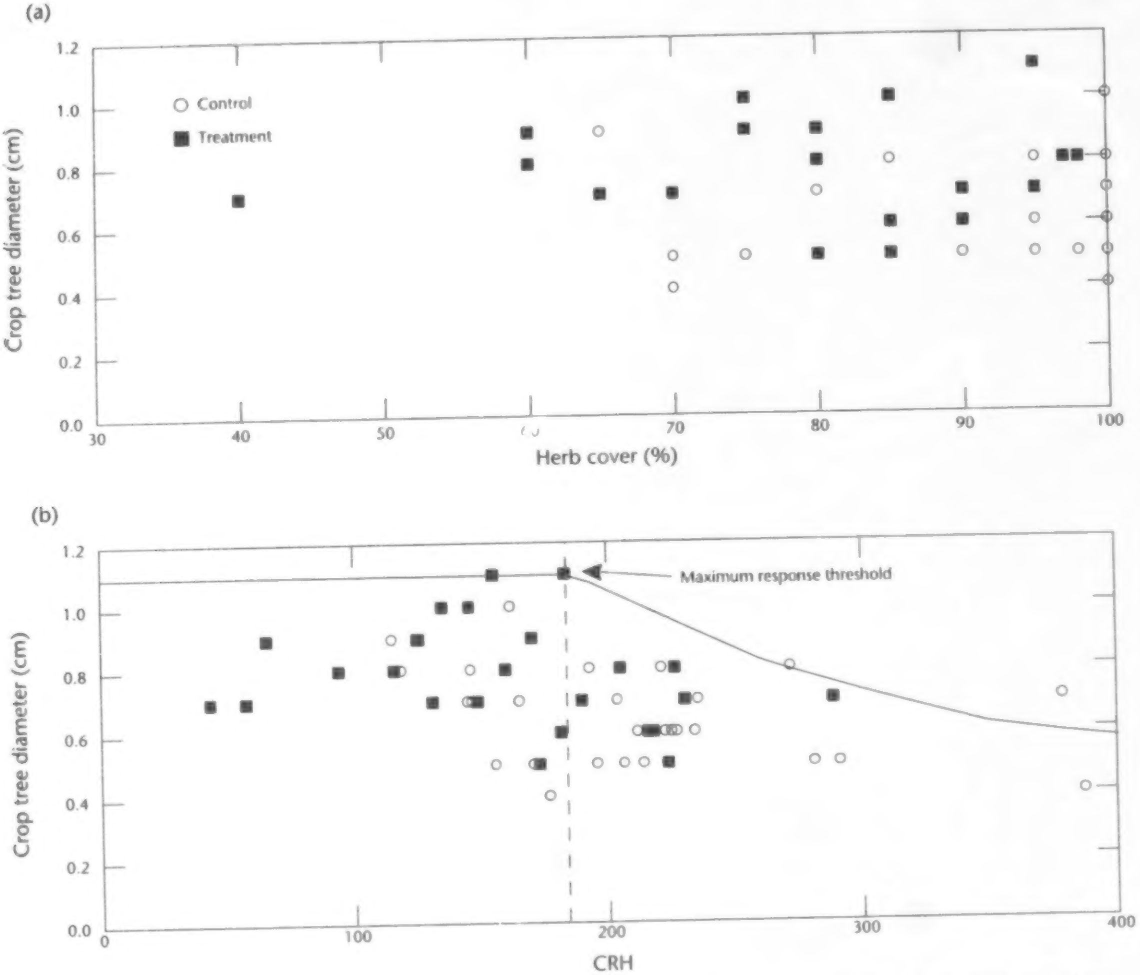


FIGURE 82 *Relationship between stem diameter of Engelmann spruce growing amongst the Subalpine Herb Complex and (a) herb cover or (b) CRH, where CRH = (herb cover * herb modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 13 (n = 37). (a) No response threshold was evident where herb cover was used as the competition index. (b) Where CRH was used as the competition index, maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover and CRH values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

DISCUSSION

Here we discuss fifth-year responses of Engelmann spruce seedlings and the *Ericaceous Shrub* Complex to manual cutting applied from mid-July to mid-September. There has not yet been adequate replication of *Subalpine Herb* Complex sites to carry out analysis.

Conifer Response

Survival of Engelmann spruce seedlings improved within 3 years of manual cutting, even though the impact on the *Ericaceous Shrub* Complex was not severe. By year 5, seedling survival was 89% in the treatment compared to 71% in the control. About three-quarters of mortality in the control was attributed to competing vegetation, compared to less than half the mortality in the treatment. Reducing vegetation abundance in a small radius apparently reduced damage to seedlings, even though the overall effect on vegetation in our 10 m^2 ($r = 1.78$ m) assessment plots was relatively small.

Five years after manual cutting, seedlings in the treatment had 22% (1.3 cm) longer leaders than those in the control, but there were no significant differences in seedling height. Nor were there significant differences in stem diameter, even though diameter increment was larger in year 3. Coates et al. (1991) found that partial removal of ericaceous shrub–dominated vegetation resulted, after 1 year, in improved Engelmann spruce stem diameter, but not height. Seedling stem diameter commonly responds to treatment sooner (often within 1–3 years) than does height (e.g., Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c). In our study, seedlings were physiologically young enough (≤2 years old) to respond to treatment, and the marginal improvements suggest that growth limitations were partially relieved by brushing. Height:diameter ratio was lower among treated seedlings by year 5 (49.6 in the treatment versus 54.2 in the control).

Preliminary results from an unreplicated PROBE trial in the *Subalpine Herb* Complex suggest that Engelmann spruce seedling growth may be unaffected by a single-pass sheep-grazing treatment (Mather and Simard 1997d; Appendix 1). Repeat grazing is considered necessary to release seedlings from competition (Newsome et al. 1995).

Plant Community Response

Manual cutting significantly reduced overall vegetation height and cover, as well as height and cover of the shrub layer for 1 year, but reductions were relatively small (e.g, 12% reduction in shrub cover and 10 cm reduction in shrub height). By year 3, differences in vegetation height and cover were no longer significant. In part, changes in vegetation abundance were small because cutting was usually applied in a smaller radius than the protocol assessment radius. This resulted in the inclusion of both cut and uncut vegetation in height and cover estimates.

On sites where vegetation under the shrub canopy is composed mainly of rhizomatous herbs rather than mosses, manual cutting of the *Ericaceous Shrub* Complex has the potential to stimulate development of a vigorous *Subalpine Herb* community (Boateng and Comeau 1997a). This did not occur on our sites, however, possibly because reductions in the shrub canopy were relatively minor. In contrast, other non-replicated PROBE trials showed that the herb layer increased in abundance following glyphosate treatment of the *Ericaceous Shrub* Complex. After 3 years, growth of spruce seedlings appeared unaffected, possibly because competitive stresses had partially shifted from shrubs to herbs (Mather and Simard 1998p; Appendix 1). A well-developed *Subalpine Herb* Complex can be difficult to manage because it recovers rapidly from both manual and chemical treatments. An unreplicated PROBE study also showed that the *Subalpine Herb* Complex recovered from a single sheep-grazing treatment within one season (Mather and Simard 1997d; Appendix 1).

The four *Ericaceous Shrub* Complex sites that received manual cutting treatments in this study had different target shrubs, thereby precluding statistical analysis of the responses of individual species. In general, however, ericaceous shrubs recovered within 5 years on the lower-elevation sites (1450 and 1475 m) in the ESSFvc and ESSFwc2, but not on the higher-elevation sites (1700 and 1800 m) in the ESSFwc4 and ESSFdk due to their slower growth rates. On the unreplicated sites, glyphosate at 2.0–2.1 kg ai/ha applied in early September had a moderate to severe impact on rhododendron, false azalea, and black huckleberry (Mather and Simard 1998p and unpublished data; Appendix 1), supporting the results of several other studies (e.g., Boyd et al. 1985; Simard 1989b; Thompson 1989; Lloyd and Heineman 1994c).

Manual cutting increased diversity, but not richness, of individual vascular plant species within the 5-year measurement period (Table 70). It also increased the diversity of structural vegetation groups associated with the *Ericaceous Shrub Complex* during that period (Table 71). Following cutting, it is likely that decreased abundance of prominent shrubs such as white-flowered rhododendron, Sitka mountain-ash, and thimbleberry allowed several minor herbaceous species to either invade the site or increase in cover. For example, the presence of pearly everlasting, sweet cicely, and various sedges increased in treated plots on two of four sites, and numerous other herbs increased in cover on one site only. The increase in diversity following cutting reflects a more even distribution of cover over a greater number of species, compared with the control where the community was dominated by a few high-cover shrub species.

Several berry-producing shrubs that are important to wildlife were present on these sites (e.g., black huckleberry, oval-leaved blueberry, red raspberry, elderberry, and thimbleberry), but only thimbleberry was reduced in abundance by the cutting treatment. Chemical brushing has more potential to reduce the availability of wildlife food and cover, however, since data from non-replicated PROBE sites showed that it killed a large proportion of ericaceous shrub stems and reduced the abundance of black huckleberry.

Effects of the Community on Resource Availability

In many high-elevation ecosystems of the southern interior of British Columbia, the short growing season, cold and wet soils, low air temperature, and heavy snowpack can limit performance of conifer seedlings, and these conditions can be exacerbated by the presence of dense vegetation. Farnden (1994) suggests that management of thermal regimes is an important consideration in preparing silvicultural prescriptions for the ESSF zone, and it follows that preparing and planting sites promptly following harvest can reduce the negative effects of vegetation on seedlings, and may even eliminate the need for brushing (Hart and Comeau 1992). However, not all ESSF sites are extremely harsh climatically; recent monitoring in the ESSF near Sicamous suggests that cloudy weather and high summer temperatures reduce the severity of the high-elevation environment (A. Vyse, pers. comm., 2000).

The short growing season is a more serious growth limitation than vegetation competition on high-elevation sites, and mechanical site preparation techniques such as mounding can lengthen favourable thermal regimes more so than brushing. Length of the growing season is governed mainly by soil temperature and the number of degree-days above 5°C. Low soil temperature, which is exacerbated by lengthy periods of snow cover and dense vegetation, limits seedling performance by delaying bud burst, reducing rates of photosynthesis, and restricting water and nutrient uptake (Kaufmann 1975; Lopushinsky and Kaufmann 1984; Goldstein et al. 1985; Grossnickle 1987). Coates et al. (1991) found that soil temperature, air temperature, and light levels were the primary factors controlling spruce seedling performance on an ericaceous shrub–dominated site in the southern interior ESSF zone. In that study, the magnitude of seedling response was directly related to the extent of vegetation and forest floor removal, with the greatest response occurring where both shrubs and herbs had been completely eliminated, and mineral soil exposed. In our study, small reductions in vegetation abundance resulted in marginal improvements in seedling growth, but the effects on resource availability and conditions were not measured. Across six southern interior ESSF sites, Balisky and Burton (1995) found that vegetation cover was the best predictor of soil temperature; however, brushing alone, without removal of the forest floor, is unlikely to result in large improvements in soil thermal regime. In practical terms, brushing treatments that completely remove vegetation are not possible, and neither are they desirable because of the potential for harming long-term site productivity, biodiversity, wildlife values, and soil stability. Retaining some shrub cover on high-elevation sites reduces the effects of snow creep and distributes snow weight more evenly around seedlings (Scagel et al. 1989). Shrubs also reduce the potential for seedling damage from high-intensity light at very high elevations (Ronco 1970), although this problem has never been documented in British Columbia. Summer frosts are also potentially damaging to newly planted seedlings, and low vegetation canopies such as that of the *Ericaceous Shrub* Complex sometimes protect seedlings from damage and sometimes do not (Stathers 1989). Coates et al. (1991) recorded the least summer frost damage in plots where vegetation had been completely removed and mineral soil exposed, likely because a greater amount of heat was re-radiated during the night. In our study, frost was rarely recorded as a damaging agent.

Competition Thresholds

In the *Ericaceous Shrub* Complex, competition thresholds for stem diameter of 0- (newly planted) to 6-year-old Engelmann spruce averaged 52% for ericaceous shrub cover and 73 for CRH. The thresholds were vague and high on almost all sites. Below the thresholds, stem diameter was highly variable among both treated and control trees, reflecting the genetic, microsite, initial size, and damage variability among the seedlings. Seedling diameter declined gradually above the thresholds, especially those based on shrub cover, suggesting that competition from ericaceous shrubs at high cover values was an important but not necessarily the sole constraint on growth. Low air and soil temperatures have been shown as primary growth-limiting factors on these sites, and simple reductions in shrub cover may not necessarily relieve these constraints.

Our data suggest, however, that lowering ericaceous shrub cover below the thresholds should reduce competitive constraints and provide the opportunity for marginally greater spruce growth. Manual cutting was successful at reducing average shrub cover below the cover threshold (from 60% to 48% cover) after 1 year, which corresponded with substantial improvements in spruce survival and small increases in leader growth. Long-term yield of the stands should improve because of the survival response to brushing, but possibly not because of the small growth response. This growth projection is supported by the finding that only 2% of brushed trees growing below the competition thresholds achieved ≥80% of the maximum growth measured on the sites.

Brushing the *Ericaceous Shrub* Complex may stimulate development of a vigorous *Subalpine Herb* Complex, effectively shifting competitive effects from one species group to another. In our study, reducing shrub cover from 60 to 48% did not result in a community shift, possibly because shrub cover remained high and the forest floor was not disturbed. However, the potential for community shifts, and the intimate mosaic of the two communities that usually occurs on these sites, suggest that competition thresholds should take into account the abundance of both shrubs and herbs. A competition threshold for the *Subalpine Herb* Complex was not evident when herb cover was used as a competition index, and was high (184) when CRH was used. These results suggest that seedlings were responding to a more complex set of limiting factors than simply the abundance of neighbouring herbs.

Competition thresholds for seedlings growing among the *Ericaceous Shrub* and *Subalpine Herb* complexes have not previously been identified in other studies. Coates et al. (1991) found that mean diameter of spruce was slightly affected by partial shrub and herb removal, and was 44% larger with complete shrub and herb removal. In shrub- and herb-free environments, mean spruce diameter was 20% greater where mineral soil was exposed and soil temperatures elevated. The results of Coates et al. (1991) suggest that diameter growth may not increase much where shrub or herb abundance is reduced to below our thresholds, possibly because the forest floor and mineral soil are not exposed and growth-limiting soil temperatures therefore not improved. Nevertheless, the effects of graded shrub and herb removals were not tested by Coates et al., and our improvements in survival, height growth, and diameter distribution below the thresholds suggest that moderate shrub reductions are sufficient to alleviate some constraints. Clearly there is a need to experimentally test the competition thresholds empirically derived in this study.

Effectiveness of Treatment at Meeting Management Objectives

Brushing is often prescribed to improve survival and growth, and to help meet free-growing criteria as set out by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). For our study sites, the Code specifies target stocking of 1200 (minimum 700) well-spaced stems/ha, and that within 12–20 years of plantation establishment (15–20 years for the ESSFdk), seedlings must be a minimum of 0.8 m tall and 100% as tall as surrounding vegetation.

Manual brushing of the *Ericaceous Shrub* Complex resulted in large increases in Engelmann spruce seedling survival, which probably improved chances of successful regeneration of these sites. There was an 18% increase in seedling survival in the manual cutting treatment by year 5, which we presume will contribute to meeting stocking requirements. Manual brushing also reduced the percentage of overtopped seedlings, which should reduce the risk of physical damage from snow- and vegetation-press. Improvements in seedling growth were minor, however, and seedling height growth continued to be slow. Five years after brushing, the 5- to 7-year-old seedlings were increasing in height at rates of 7.1 cm/yr in the treatment and 5.8 cm/yr in the control, which is below the average for interior spruce of similar age (Vyse 1981). At the present rates of height growth, seedlings in the treatment will attain the minimum height (0.8 m) 8.5 years after manual cutting and those in the control will do so after 9.3 years, on average. On the basis of our conifer and vegetation height measurements, we predict the conifer:vegetation height ratio requirement (B.C. Ministry of Forests 2000) will be met approximately 10 years after brushing (when seedlings are 10–12 years-old) in the treatment and after approximately 14 years (when seedlings are 14–16 years old) in the control (Figure 83). However, stocking requirements may not be met in the control if survival continues to decline. This indicates that even minor reductions in abundance of the *Ericaceous Shrub* Complex can help seedlings meet free-growing.

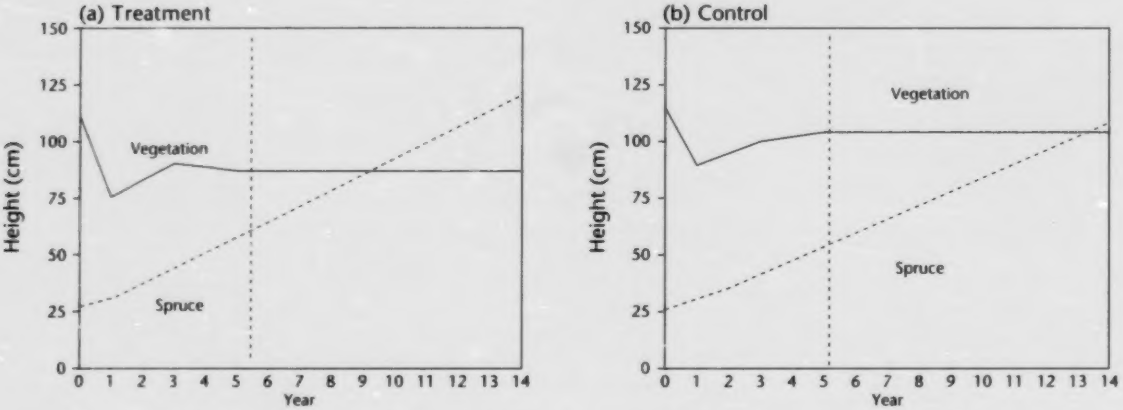


FIGURE 83 *Comparison of average spruce and vegetation height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ESSF* Ericaceous Shrub *Complex. Heights for years 0 through 5 are based on actual data (values for years 2 and 4 were interpolated), and the heights for years 6 through 14 are projected on the basis of height growth rates in year 5. The vertical broken line indicates the most recent assessment year. Spruce are predicted to outgrow vegetation 10 years after manual cutting and after 14 years in the control.*

CONCLUSIONS

Manual brushing of the *Ericaceous Shrub* Complex resulted in a large improvement in survival of young Engelmann spruce seedlings. There were also marginal increases in seedling growth. Abundance of the shrub layer was reduced for less than 3 years, and there were no increases in herb height and cover as a result of cutting shrubs. However, the effects of cutting on vegetation may have been underestimated because it was assessed, according to PROBE protocol, in a 1.78-m plot radius, whereas the cutting radius ranged from 0.5 to 2.0 m. This often resulted in the inclusion of both treated and untreated vegetation in the assessment plots. In spite of the small response of conifers, brushing is expected to contribute to meeting both stocking and conifer:vegetation height ratio requirements for free-growing (B.C. Ministry of Forests 2000).

Continued monitoring of these sites is necessary to determine whether fifth-year growth and survival responses will be biologically meaningful over the long term. The small increase in growth may have little effect on yield or rotation length, but the substantial improvements in survival and stocking have important implications for stand yield.

1. Manual cutting improved fifth-year survival of Engelmann spruce seedlings by 18%. Our results suggest that, on sites where the *Ericaceous Shrub* Complex becomes well-developed as a result of delayed planting, stocking requirements may not be met without brushing. Survival problems may be minimized, however, where sites are mechanically prepared and planted with large stock immediately after harvest.
2. Growth of spruce seedlings improved marginally following brushing, which is consistent with the minor effect that manual cutting had on vegetation. Other studies involving the *Ericaceous Shrub* Complex have shown that seedling growth responses are positively correlated with the degree of vegetation and forest floor removal, and with concomitant increases in soil temperature. Long-term measurements are required to determine whether small growth improvements, such as those measured in our study, will be biologically meaningful over the long term.
3. Competition thresholds for spruce diameter growth were 52% shrub cover and 73 CRH in the *Ericaceous Shrub* Complex. In the *Subalpine Herb* Complex, a threshold was not evident based on herb cover, and it was large based on CRH. Reducing ericaceous shrubs below the shrub thresholds should slightly improve spruce diameter growth.
4. The *Ericaceous Shrub* Complex often occurs in a mosaic with the *Subalpine Herb* Complex. Caution should be exercised when treating shrub communities that have a well-developed herb layer under the canopy. The herb community can increase rapidly in response to removal of the shrub layer, and may be difficult to treat because of its ability to recover rapidly from treatment.
5. The *Ericaceous Shrub* Complex develops slowly, and may not require brushing if sites are prepared and planted promptly following harvest. Backlog NSR is gradually being eliminated in southern interior British Columbia, so the need to release seedlings from a fully developed *Ericaceous Shrub* Complex should therefore be diminishing.
6. Manual cutting did not reduce the abundance of wildlife food plants (except thimbleberry) in our study, and it increased the diversity of vascular species. However, the increase in diversity resulted from an increase in the abundance of ruderale species.

SECTION 8

Dry Alder Complex

ABSTRACT

We have fifth-year results demonstrating the effects of manual cutting on established (5–7-year-old) lodgepole pine seedlings and the *Dry Alder* Complex in the MS zone. The *Dry Alder* community commonly occurs with sufficient abundance to suggest that it is hindering conifer performance and/or the ability to meet free-growing, but we found no evidence of this. Pine performed well regardless of brushing, and, although manual cutting reduced the abundance of alder, it did not improve seedling survival, vigour, or growth. Brushing immediately improved the competitive status of pine stands, but control pine naturally outgrew the alder and met free-growing requirements within 1 year of those in the treatment. Competition thresholds for pine stem diameter growth were identified at 33% alder cover and 38 CRH. However, most pine trees naturally grew in neighbourhoods below these thresholds, and the few that may have benefited from brushing did not significantly improve average performance after treatment. Manual cutting had no effect on richness or diversity of vascular species associated with the *Dry Alder* Complex.

Description of the *Dry Alder* Complex

Sitka alder (*Alnus viridis* ssp. *sinuata*) is the dominant species of the *Dry Alder* Complex, and willow (*Salix* spp.) is also present on some sites (Figure 84). Characteristic understorey species are fireweed (*Epilobium angustifolium*) on sites mesic and wetter, and pinegrass (*Calamagrostis rubescens*) on sites drier than mesic (Kimmins and Comeau 1990). Thimbleberry (*Rubus parviflorus*) may also be prominent in the understorey on some sites. The *Dry Alder* Complex is most common in the MS zone, where it occurs in all subzones. It is also found in the ICH and SBS zones, and at upper elevations of the IDF zone and lower elevations of the ESSF zone. The *Dry Alder* community also occurs in the BWBS zone of northeastern British Columbia.

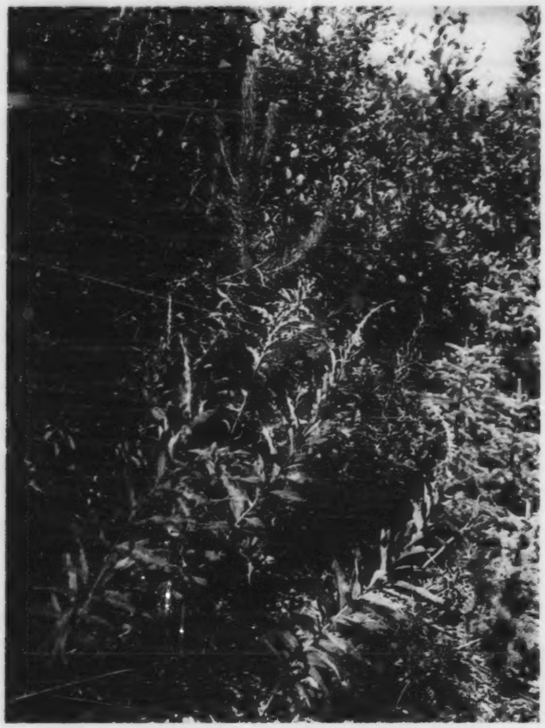


FIGURE 84 *The Dry Alder Complex prior to manual cutting at Buck Creek (Site 4) in the MSdc variant in the Lillooet Forest District. Photo credit: Jean Mather.*

The *Dry Alder* Complex occurs on a range of soils and parent materials, but is most common on moderately well- to well-drained, coarse to loamy textured Brunisols and Luvisols (Boateng and Comeau 1997f). It occurs predominantly on north and east aspects. The complex develops mainly on submesic to subhygric sites, and does not become abundant on either very wet sites with a high water table, or on subxeric or drier sites sites that are prone to drought. Sitka alder lacks the physiological adaptations needed to prevent moisture loss from the foliage, and is thus poorly adapted to drought (Haeussler et al. 1990).

Development of the *Dry Alder* Complex

Sitka alder is often present under mature lodgepole pine forests in the southern interior of British Columbia, but because it is only moderately shade tolerant (Krajina et al. 1982), it tends to remain suppressed until light is increased following logging. Ground disturbance during logging, mechanical site preparation, and burning enhance alder and willow abundance by providing a favourable seedbed and by damaging the root crowns of existing plants, thereby stimulating sprout growth. Clean-cut and shattered stumps are reported to sprout equally well (Haeussler et al. 1990). Mechanical site preparation of established alder communities (e.g., backlog sites) stimulates sprouting and simply results in renewal of the complex. Practices that hinder development of the complex include severe fire or mechanical disturbances that destroy roots, and incomplete removal of the overstorey canopy.

Wind-borne seed from alder and willow plants in the vicinity of logged areas contributes to development of the *Dry Alder* Complex. Germination of both species is favoured by seedbeds that are burned or have exposed mineral soil, and receive sunlight. Alder is a nitrogen-fixing pioneer species that can establish on sites that have been severely disturbed with little organic matter remaining. Alder produces good seed crops every year from plants that are 6–8 years old and bumper crops every 3–5 years, while willow produces prolific quantities of seed annually. Alder seeds disperse during late fall and winter and germinate the following spring. Willow seeds usually germinate within 2 weeks after dispersal in the spring. Seeds of both species can travel long distances by wind (Haeussler et al. 1990).

Growth of young alder plants ranges from 20 to 120 cm/yr depending on origin of the plants and site quality. Willow tends to grow faster than alder; new sprouts commonly grow at a rate of 60–200 cm/yr. Sprouts from cut or burned alder or willow plants grow faster than plants established from seed, but, regardless of origin, growth slows with age of the plants. By age 10–15 years, we observed that average height growth of alder has slowed to 10–20 cm/year. Growth may slow sooner on poor sites than on better sites (Haeussler et al. 1990).

The *Dry Alder* Complex is typically fully developed 3–20 years after harvest (Boateng and Comeau 1997f). Extensive areas of continuous alder and willow do not commonly develop. Rather, clumps of multi-stemmed bushes are found interspersed with open areas. We observed that alder typically reaches 2 m in height and 30% cover 10 years after disturbance on sites in the southern interior of British Columbia (Table 75). At full maturity, alder cover and height average 30–50% and 3–4 m, respectively (Boateng and Comeau 1997f).

Conifer regeneration (either natural or artificial) tends to be accomplished relatively easily on sites where the *Dry Alder* Complex develops, and full stocking is usually obtained before the alder becomes well established. Lodgepole pine is the dominant conifer associated with the *Dry Alder* Complex.

Interactions with Conifers

The *Dry Alder* Complex is one of the vegetation communities identified as a competitive threat to conifer seedlings in the southern interior of British Columbia (Kimmins and Comeau 1990). However, because of its low, bushy form and relatively slow growth rate (Harrington and Deal 1982), it is likely a less serious problem than tall broadleaf trees. The resources that Sitka alder competes for and its effect on seedling microenvironment apparently vary depending on site characteristics. For instance, on a mesic site in the MS zone, Simard (1990b) found that Sitka alder reduced light availability for lodgepole pine and depressed soil temperatures, but did not affect the availability of moisture in the rooting zone. However, competition is always more problematic on resource-limited sites (e.g., Harper 1977; Radosevich and Holt 1984), and water availability may be limiting on dry sites or where alder densities are especially high. In a study involving red alder (*Alnus rubra*), Shainsky and Radosevich (1992) found that alder was not a particularly good competitor for soil water, but at high densities it reduced water availability to Douglas-fir.

TABLE 75 *Average height and cover of Sitka alder in the MS Dry Alder Complex 10–15 years after site disturbance*

Years since disturbance	Cover (%)	Height (cm)
10	29.3	203.6
11	34.7	221.0
13	41.3	240.0
15	41.0	274.6

Although resource competition can potentially have a negative effect on conifers, there are also several ways by which alder benefits seedlings. Nutrient availability, in both the short and long term, is improved as a result of alder's ability to fix atmospheric nitrogen and through annual litter inputs (Crocker and Major 1955; Cole et al. 1978; Sachs 1992). Rates of nitrogen fixation by Sitka alder vary by region, but range between 1.5 and 8 kg N/ha/yr in the southern interior (Sachs and Comeau 1991; Mead and Preston 1992). These rates are considerably lower than the 20–150 kg N/ha/yr documented for more productive coastal sites (Binkley 1981; Heilman and Ekuan 1982) and slightly lower than those reported for the SBS zone (15 kg N/ha/yr; P. Sanborn, pers. comm., 1999). Nitrogen deficiencies are common in lodgepole pine forests in the southern interior, however, and even modest nitrogen fixation rates can help maintain long-term soil productivity. Transfer of nitrogen from alder to lodgepole pine via mycorrhizal linkages has also also been observed (Arnebrant et al. 1993), and there is some indication that red alder, at least, reduces conifer damage from *Phellinus weirii* (Nelson et al. 1978).

Ideally, the *Dry Alder* Complex should be brushed only when the negative effects of alder competition outweigh the benefits of its presence. Simard (1990b) tentatively identified a competition threshold for lodgepole pine growth of 10–40% (average 33%) alder cover, with lower thresholds on wetter, higher-quality sites. Lodgepole pine growth was depressed at cover values above the threshold, but, at lower covers, pine appeared to benefit from the presence of alder. Simulations of productivity in lodgepole pine stands support the threshold of 35% Sitka alder cover to maintain long-term yield of lodgepole pine following conventional silviculture practices in the MS zone (Sachs and Comeau 1992). Thresholds in the SBS zone may be somewhat lower; Brockley and Sanborn (pers. comm., 1999) found that lodgepole pine diameter growth was greater with 10% alder cover than with no alder or 20–40% alder cover.

Importance to Wildlife and Range

Sitka alder is a major food source for snowshoe hares (Hansen and Flinders 1969), the catkins are readily eaten by squirrels (Harestad 1983), and cones, buds, and seeds are eaten by some birds (Healy and Gill 1974). It has limited value as a browse for ungulates (Healy and Gill 1974), but it provides cover for them and for small mammals such as snowshoe hares, red squirrels, and voles (Sullivan 1985).

Sitka alder communities are often utilized by free-ranging cattle. Although Sitka alder is not commonly grazed, seeded domestic grasses and some herb species in the *Dry Alder* Complex are preferred forage for cattle (McLean and Tisdale 1960; Willms et al. 1980). Range and silviculture objectives may conflict in this complex, and chemical brushing treatments, in particular, can reduce forage abundance (Simard, Heineman, and Youwe 1998).

Common Brushing Treatments in the *Dry Alder* Complex

The brushing treatments most commonly applied to the *Dry Alder* Complex for conifer release in British Columbia are manual cutting, foliar glyphosate application, and cut stump glyphosate. Manual cutting is by far the most common of these treatments. Details on timing, tools, and costs associated with the various treatments are provided in Table 76.

TABLE 76 *Common brushing treatments applied to the Dry Alder Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Create a free-growing stand 2. Reduce competition for light	Any time[b]	1	1. Power saw 2. Motorized brush saw	$538 $538	1. Resprouting
Foliar glyphosate (1.4-2.1 kg ai/ha)	1. Create a free-growing stand 2. Reduce competition for light	Mid-June to October[b]	1	1. Backpack sprayer 2. Fixed-wing plane or helicopter (aerial)	$700 $311	2. Possible reduction in site productivity[c] 3. Extended reduction in alder abundance may negatively affect wildlife 4. Difficulty obtaining herbicide permits
Cut stump–glyphosate (10% soln.)	1. Create a free-growing stand 2. Reduce competition for light	Unknown	1	1. Saw and backpack sprayer or squirt bottle	Unknown	1. Time consuming 2. Possible reduction in site productivity[c] 3. Extended reduction in alder abundance may negatively affect wildlife 4. Difficulty obtaining herbicide permits

[a] Based on average costs for the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)

[b] Lloyd and Heineman (1994b)

[c] Sachs and Comeau (1992)

Manual Cutting

Lodgepole pine in the MS zone

This section describes fifth-year lodgepole pine and vegetation responses to manual cutting of the *Dry Alder* Complex in the MS zone (n = 3). Seedlings were 5–7 years old at the time of treatment.

Description of study sites and treatments

Study sites for this treatment cell are distributed throughout the Kamloops Forest Region. The Slate Creek site is located 20 km east of Princeton in the Merritt Forest District, the Buck Creek site is 20 km northwest of Lillooet in the Lillooet District, and the Ross Lake site is 35 km southeast of Kamloops in the Kamloops District. The Slate Creek site occurs in the Thompson Dry Mild MS variant (MSdm2), the Buck Creek site in the Dry Cold MS subzone (MSdc), and the Ross Lake site in the Very Dry Cool MS subzone (MSxk).

Physiographic features, logging and site preparation history, and conifer and vegetation characteristics at the time of brushing were similar at each site (Table 77). Sites are classified as site series 01 (mesic), with 20–35% slope, north or northeast aspect, sandy loam Brunisolic or Podzolic soils, and elevations of 1200–1420 m.

The original stands were clearcut in 1980–1982 (10–14 years before brushing), and no site preparation was done. Lodgepole pine was planted 3–9 years after ground disturbance. Planted pine were 5–7 years old at the time of treatment, and alder was the dominant non-crop species, having 18–28% cover and a height of 1.7–2.1 m.

Most pine were growing between alder clumps, not inside the clumps. An average of 21% of the pine were overtopped by vegetation and 25% were free of vegetation. Most pine were of moderate or good vigour; few trees were unhealthy. The sites were well stocked with 2670–7853 conifers/ha (Table 77), and lodgepole pine was the dominant species. Alder was of moderate to good vigour at the time of brushing; average annual growth was 15–25 cm/yr. On all sites, pine was growing faster than the untreated alder; pine leader growth at the time of treatment was 20–45 cm/yr.

All three sites were brushed between mid-August and mid-September using power saws and motorized brush saws (Table 78). Alder was cut near the root collar.

Conifer response

Survival and vigour Lodgepole pine survival was excellent (average 100%, p = 0.42) (Table 79) in the treatment and control 3 years after manual cutting, and continued to be excellent (average 98%, p = 0.42) in year 5, when seedlings were 10–12 years old. A small amount of mortality was caused by vegetation competition in the control (1%) and cattle damage in the treatment (4%). Fifth-year silviculture survey information showed an average 883 stems/ha were free-growing according to the old guidelines (B.C. Ministry of Forests 1995a), with no significant difference between the treatment and the control (p = 0.36).

Vigour of planted pine was similar in the manual cutting treatment and control throughout the 5-year monitoring period (Figure 85). Leaving alder untreated did not reduce the vigour of pine stands, nor did manual removal of alder improve the vigour of most treated trees. There were few (4–8%) poor-vigour trees both before and after treatment. The percentage of good-vigour trees increased from 37 to 55% in the treatment and from 34 to 40% in the control during the 5-year measurement period.

Poor-vigour trees usually occurred inside dense alder clumps or, less commonly, inside dense patches of naturally regenerated lodgepole pine. They tended to remain poor in vigour during the 5-year measurement period, regardless of treatment. Because stocking was consistently within range of target requirements, and healthy trees were distributed throughout the blocks, it will be of little consequence to the productivity and health of the stands if these few poor-vigour trees remain unhealthy, or even die.

Growth Five years after manual cutting, there were no significant differences in lodgepole pine height, leader length, stem diameter, diameter increment, or height:diameter ratio between the treatment and control (p>0.10) (Table 79). Prior to cutting, seedlings averaged 141.4-cm tall with 28.8-cm leaders, and 5 years later at age 10–12, they averaged 320.2 cm tall with 42.2-cm leaders. Stem diameter increased from 2.98 to 6.47 cm during the 5-year

TABLE 77 *Characteristics and history of the three replicate study sites where the MS Dry Alder Complex was manually cut in lodgepole pine plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Slate Creek PROBE 23 Merritt District	MSdm2 01 (mesic)	1380	N 25%	Brunisol/ sandy loam	Clearcut 1982	10	n/a	3	P 1985	2+0 BR	7	251 (38)	Alder cover: 18 (16) Alder height: 196 (112)	4656	1200
Buck Creek PROBE 4 Lillooet District	MSdc 01 (mesic)	1420	NE 35%	Podzol/ sandy loam	Clearcut 1981	10	n/a	4	P 1985	PSB 211 1+0	6	66 (18)	Alder cover: 28 (20) Alder height: 210 (52)	7853	1164
Ross Lake PROBE 55 Kamloops District	MSxk 01 (mesic)	1200	N 20%	Brunisol/ sandy loam	Clearcut 1980	14	n/a	9	P 1989	PSB 211	5	107 (37)	Alder cover: 20 (13) Alder height: 168 (69)	2670	1128

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting

[b] Origin: P = planted; N = natural regeneration

[c] Age refers to the number of years since planting

[d] Values are means and one standard deviation (in parentheses)

TABLE 78 *A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the MS Dry Alder Complex*

Site	Initial treatment date	Treatment type	Treatment tool	Repeat treatment
Slate Creek	September 1992	Broadcast	Power saw	None
Buck Creek	Mid-August 1991	Broadcast	Power saw and brush saw	None
Ross Creek	Mid-September 1994	Patches of alder left	Power saw	None

TABLE 79 *Survival and growth responses of lodgepole pine seedlings to manual cutting in the MS Dry Alder Complex*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	99	100	0.907	0.42
3 yr post-treatment	99	100	0.907	0.42
5 yr post-treatment	96	99	2.065	0.42
Stem diameter (cm)				
Pre-treatment	3.03	2.92	0.283	0.82
1 yr post-treatment	3.97	3.86	0.424	0.87
3 yr post-treatment	5.04	4.87	0.520	0.83
5 yr post-treatment	6.58	6.36	0.653	0.83
Diameter increment (cm)				
1 yr post-treatment	0.78	0.69	0.114	0.66
3 yr post-treatment	0.66	0.68	0.104	0.91
5 yr post-treatment	0.77	0.75	0.063	0.84
Height (cm)				
Pre-treatment	144.5	138.2	8.317	0.65
1 yr post-treatment	186.3	193.2	12.439	0.73
3 yr post-treatment	244.2	252.0	16.686	0.77
5 yr post-treatment	317.1	323.4	23.855	0.87
Leader length (cm)				
Pre-treatment	29.1	28.5	2.103	0.87
1 yr post-treatment	29.9	36.1	3.241	0.31
3 yr post-treatment	34.6	37.8	3.263	0.55
5 yr post-treatment	46.2	38.1	4.696	0.35
Height:diameter ratio				
Pre-treatment	47.4	45.5	2.805	0.67
1 yr post-treatment	45.6	48.9	2.170	0.40
3 yr post-treatment	47.6	51.3	2.315	0.37
5 yr post-treatment	47.8	50.9	1.477	0.28

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

measurement period, and height:diameter ratio increased slightly from 46.5 to 49.4.

Both diameter and height distributions for lodgepole pine were approximately normal throughout the 5-year measurement period, and were similar in the treatment and control (Figures 86 and 87). This agrees with ANOVA results showing that pine diameter and height growth did not change as a result of cutting alder.

Competitive status Treated pine experienced an immediate large reduction in overtopping when alder was cut, but within 3 years, competitive status was essentially the same in the treatment and control (Figures 88 and 89). Prior to manual cutting, approximately one-quarter of seedlings were free of vegetation, half were threatened, and one-quarter were overtopped. Five years after treatment, three-quarters of treated seedlings and two-thirds of control seedlings were free of vegetation. Only 1% of treated seedlings and 10% of control seedlings continued to be overtopped.

Plant community responses

Abundance Sitka alder averaged 191.6 cm tall immediately prior to manual cutting, and 1 year later, it had recovered to a height of 70.7 cm; meanwhile, alder in the control increased in height to 250.6 cm ($p = 0.08$) (Table 80, Figure 90). Alder cover in the treatment was less than half that of the control one year after cutting, but the difference was not significant because alder recovery was so highly variable among sites. Neither were the substantial differences in alder height and cover statistically significant in years 3 and 5 ($p>0.10$) for this reason. The diverse response of alder following cutting appear not to be explained by differences in site quality, treatment date, or age, vigour, or density of alder at the time of treatment.

Manual cutting had a minor effect on the shrub layer; its cover was significantly lower in the

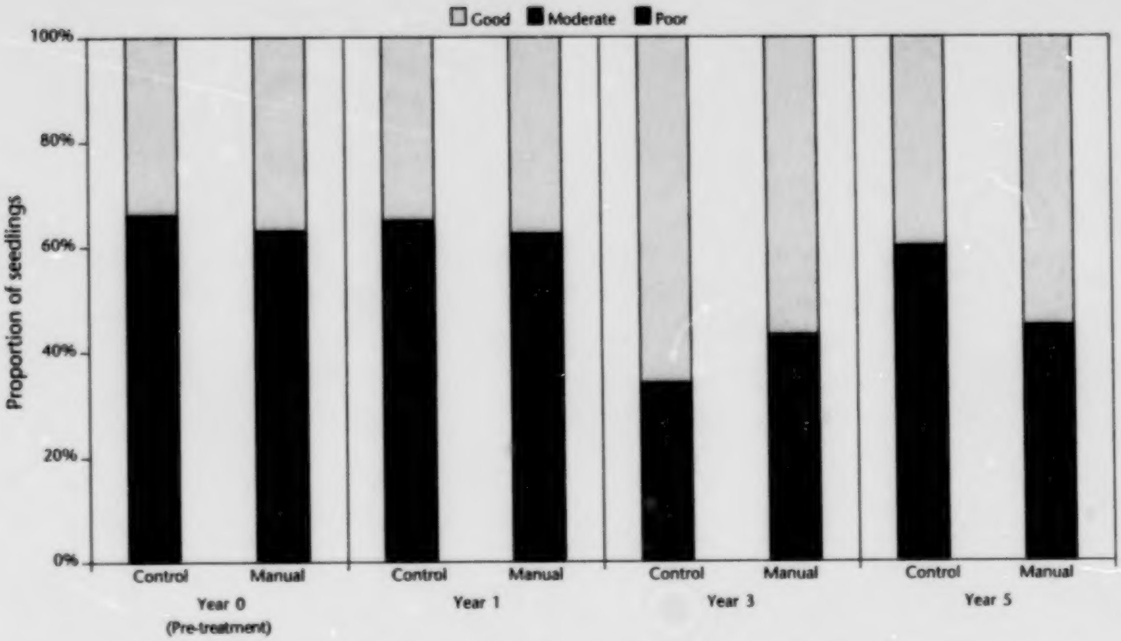


FIGURE 85 *Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the MS Dry Alder Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

treatment than the control in year 3 (37.1 versus 51.5%, p = 0.10), but the difference disappeared by year 5. Removal of the alder canopy had no effect on abundance of the herb layer during the 5-year monitoring period.

Sprouting Ninety percent of cut alder stems sprouted within 1 year of treatment (Table 81), but there was considerable variability among sites in the rate at which sprouts thinned, the average number of sprouts per stump, and sprout growth rate. The average percentage of cut stumps with sprouts decreased to 54% within 5 years of treatment because of self-thinning (range of 17–96%). One year after treatment, cut stumps averaged nine sprouts each, but these thinned to three per stump by year 3. Average sprout length was 33 cm in year 1, 88 cm in year 3, and 104 cm in year 5. Stumps tended to have a mixture of suppressed and vigorous sprouts both 1 and 5 years after cutting.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the *Dry Alder* Complex had no effect on either species richness or diversity (p>0.10) (Table 82). Species richness increased between the pre-treatment assessment (21 species) and the third-year assessment (28 species), and then decreased again by the fifth-year assessment (23 species). Changes in richness occurred equally in the treatment and control. Neither the number of structural vegetation groups nor their diversity was affected by manual cutting (p>0.10) (Table 83).

Cover data for individual species are available for only two of the three sites. On both these sites, Sitka alder predictably decreased in cover following treatment, which agrees with our ANOVA results. Thimbleberry was stimulated by removal of the overstorey alder, but other understorey shrub and herb species, including fireweed, were unaffected by treatment (Table 84).

Competition Thresholds

Competition thresholds for lodgepole pine diameter were derived using all PROBE pine sites in the *Dry Alder* Complex regardless of the brushing treatment applied. The analysis included three sites

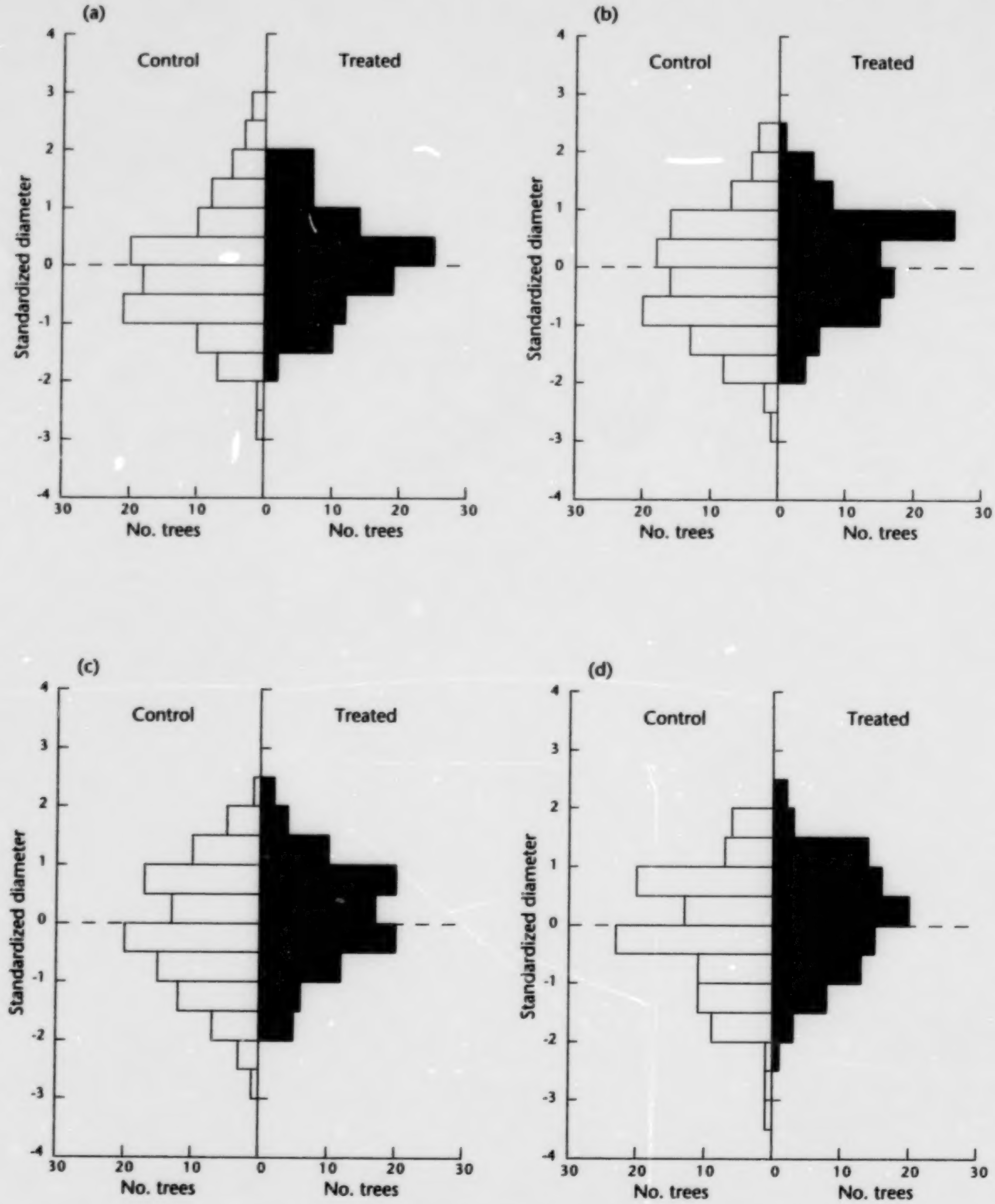


FIGURE 86 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the MS Dry Alder Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

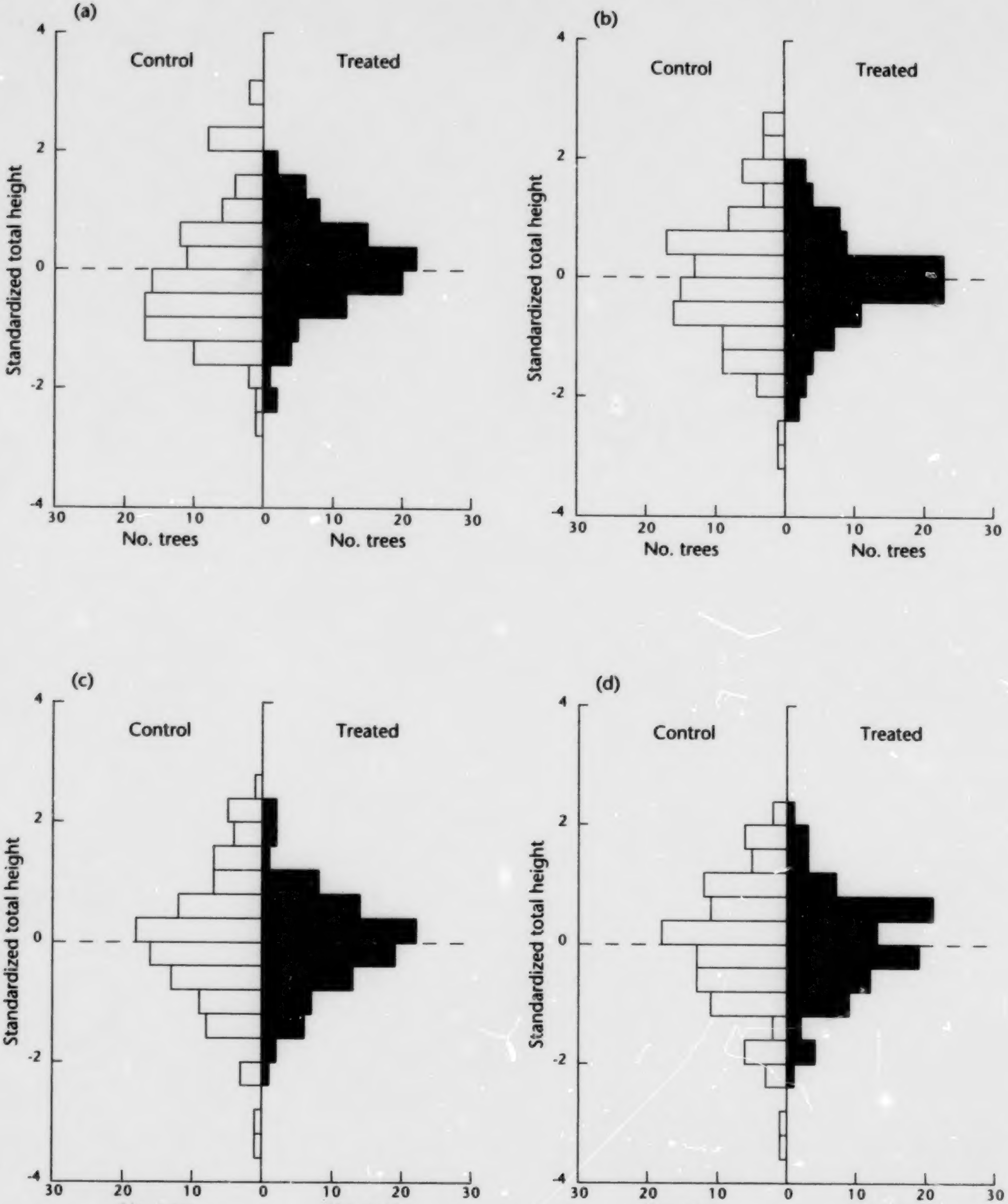


FIGURE 87 *Frequency of control and treated trees in standardized total height classes ($\mu = 0$; s.d. = 1; $n = 3$ for the control and treatment combined) for lodgepole pine in the Dry Alder Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

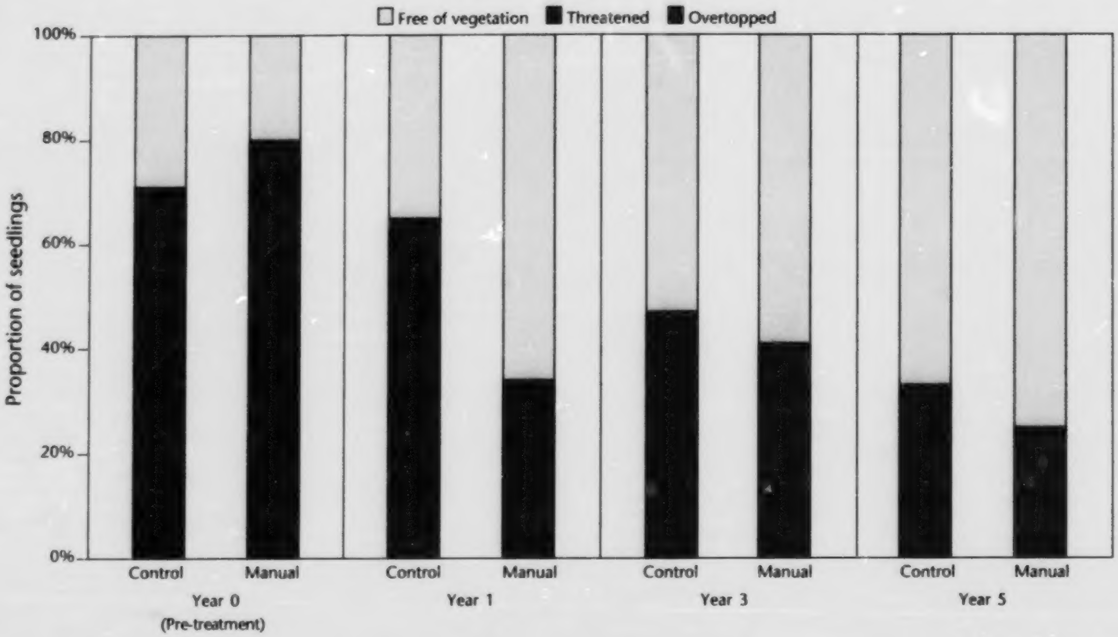


FIGURE 88 *Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the MS* Dry Alder Complex. *Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

that were manually cut and one site that was broadcast sprayed with glyphosate (n = 4). All sites were in the MS zone, and lodegepole pine age varied between 5 and 11 years old (Table 85). The thresholds were based on cover and height of Sitka alder, where CRH = (alder cover * modal alder height)/lodgepole pine height.

The Sitka alder cover and CRH thresholds for lodgepole pine diameter growth averaged 33% and 38, respectively, and varied little among the four sites (Table 85). The thresholds were not sharp on most sites, but above them there was a consistent decline in lodgepole pine diameter (e.g., Figure 91). On average, 12–20% of the trees were growing in neighbourhoods above the thresholds, and they may benefit from further selective brushing. Most (60–70%) trees above the thresholds were, on average, control trees, whereas those below were evenly split between the treatment and control. Most (80–90%) treated trees fell below the thresholds, suggesting that brushing in this complex reduced localized alder covers and potentially improved the competitive environment of most trees. However, both the means (p>0.10) (Table 79) and the distributions of pine diameters across alder neighbourhoods (e.g., Figure 91) were similar between the brushing treatment and control, indicating that pine diameter had not responded to alder reductions. In addition, only 8% of brushed lodgepole pine trees that were growing in alder neighbourhoods below the thresholds achieved ≥80% of the maximum diameter growth measured on the sites, suggesting that most brushed trees continued to be constrained by factors other than alder competition.

Linear regressions of lodepole pine diameter versus Sitka alder cover were significant for three of the four PROBE sites (p<0.10) (Table 85). However, the adjusted r^2 values were very low (0.03–0.15) and the slopes were fairly shallow (β_1 -0.002 to -0.031), suggesting that the importance and intensity of competition between pine and alder were low. This is because of the wide variability in pine diameter across the broad range in localized alder covers. Linear regressions between pine diameter and CRH had variable adjusted r^2 values (0.01–0.41) and slopes (β_1 -0.015 to -0.052). Fitting a negative exponential function to the diameter-CRH relationship did not improve the adjusted r^2 values for site 55.

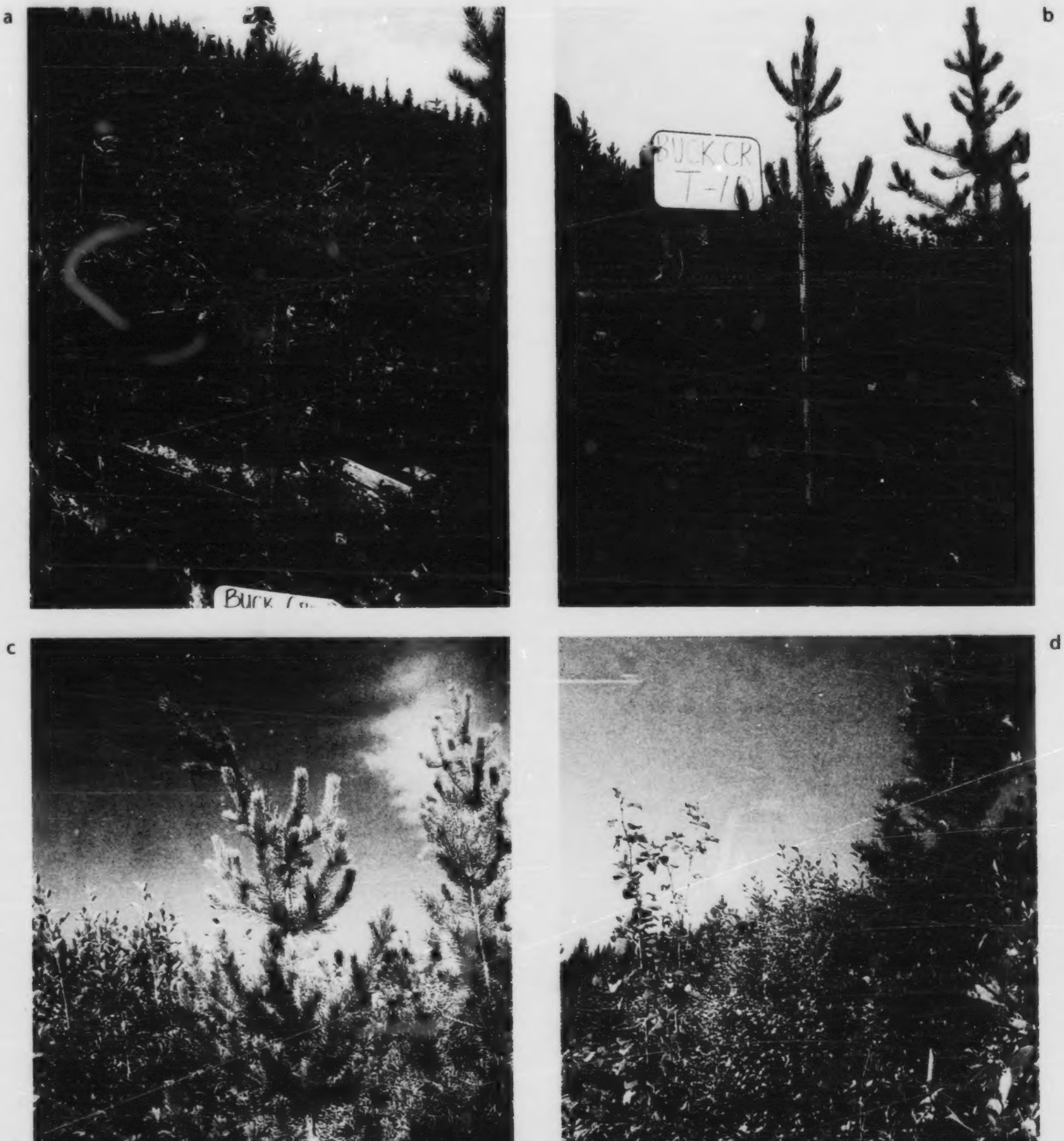


FIGURE 89 *Effects of manual cutting on the Dry Alder Complex and lodgepole pine (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Lodgepole pine outgrew the alder canopy regardless of brushing. Photo credit: Jean Mather.*

TABLE 80 *Cover and height of vegetation in the MS Dry Alder Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Sitka alder				
Cover (%)				
Pre-treatment	24.3	20.1	3.737	0.51
1 yr post-treatment	9.5	21.6	4.213	0.18
3 yr post-treatment	16.2	30.8	7.922	0.32
5 yr post-treatment	20.3	30.9	7.563	0.42
Height (cm)				
Pre-treatment	196.5	186.6	16.733	0.72
1 yr post-treatment	70.7	250.6	39.431	0.08*
3 yr post-treatment	129.0	245.0	39.696	0.17
5 yr post-treatment	164.7	254.8	26.349	0.14
Shrubs				
Cover (%)				
Pre-treatment	49.6	45.8	4.441	0.60
1 yr post-treatment	37.4	46.4	2.288	0.11
3 yr post-treatment	37.1	51.5	3.464	0.10*
5 yr post-treatment	47.5	50.8	3.410	0.56
Height (cm)				
Pre-treatment	162.6	176.7	34.225	0.80
1 yr post-treatment	85.1	192.1	32.766	0.15
3 yr post-treatment	124.1	212.0	38.488	0.25
5 yr post-treatment	143.2	227.8	22.837	0.12
Herbs				
Cover (%)				
Pre-treatment	33.8	33.6	1.534	0.92
1 yr post-treatment	34.6	35.2	3.002	0.90
3 yr post-treatment	29.1	32.1	1.271	0.23
5 yr post-treatment	30.9	31.3	3.107	0.94
Height (cm)				
Pre-treatment	70.4	72.2	4.075	0.78
1 yr post-treatment	76.2	80.0	4.617	0.62
3 yr post-treatment	80.9	82.8	3.094	0.70
5 yr post-treatment	66.2	59.6	2.810	0.24

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

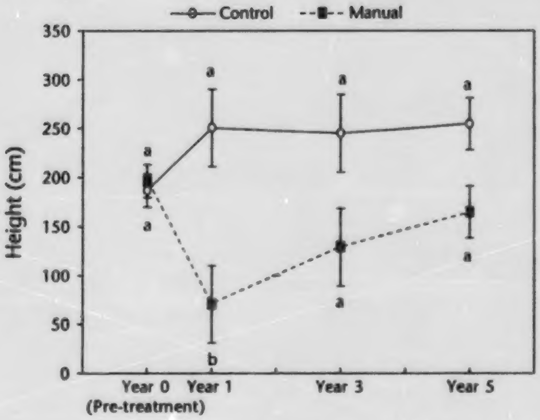


FIGURE 90 *Comparison of mean Sitka alder height between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the MS Dry Alder Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 81 *Sprouting characteristics of Sitka alder in the MS Dry Alder Complex following manual cutting*

Response variable	Mean
Proportion of stumps with sprouts	
1 yr post-treatment	90
3 yr post-treatment	65
5 yr post-treatment	54
Number of sprouts per stump	
1 yr post-treatment	9
3 yr post-treatment	3
5 yr post-treatment	4
Sprout length (cm)	
1 yr post-treatment	33
3 yr post-treatment	88
5 yr post-treatment	104

TABLE 82 *Richness and diversity of vascular plant species in the MS Dry Alder Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Richness				
Pre-treatment	20.67	21.00	1.434	0.88
1 yr post-treatment	22.00	26.33	1.546	0.19
3 yr post-treatment	26.75	28.25	2.282	0.67
5 yr post-treatment	22.00	24.00	1.871	0.53
Shannon-Weaver Diversity Index				
Pre-treatment	1.68	1.73	0.194	0.88
1 yr post-treatment	1.70	1.71	0.165	0.96
3 yr post-treatment	1.90	1.86	0.151	0.87
5 yr post-treatment	1.77	1.69	0.153	0.76
Simpson's Diversity Index				
Pre-treatment	0.73	0.73	0.052	0.98
1 yr post-treatment	0.74	0.70	0.052	0.67
3 yr post-treatment	0.76	0.73	0.042	0.59
5 yr post-treatment	0.76	0.70	0.045	0.43

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 83 *Richness and diversity of structural vegetation groups in the MS Dry Alder Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Richness				
Pre-treatment	5.67	5.67	0.000	1.00
1 yr post-treatment	6.00	5.67	0.236	0.42
3 yr post-treatment	6.25	6.50	0.177	0.39
5 yr post-treatment	6.00	5.67	0.236	0.42
Shannon-Weaver Diversity Index				
Pre-treatment	1.25	1.32	0.063	0.51
1 yr post-treatment	1.31	1.29	0.098	0.90
3 yr post-treatment	1.35	1.33	0.070	0.87
5 yr post-treatment	1.41	1.27	0.081	0.34
Simpson's Diversity Index				
Pre-treatment	0.65	0.68	0.021	0.44
1 yr post-treatment	0.67	0.65	0.044	0.80
3 yr post-treatment	0.68	0.66	0.031	0.58
5 yr post-treatment	0.72	0.64	0.035	0.28

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 84 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the MS Dry Alder Complex in lodgepole pine plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Tall shrubs		*Alnus viridis*	
Low shrubs	*Rubus parviflorus*		*Rubus idaeus*
Herbs			*Epilobium angustifolium* *Hieracium albiflorum* *Orthilia secunda*

TABLE 85 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting lodgepole pine stem diameter from the competition indices, Sitka alder cover and CRH, in the Dry Alder Complex in the MS zone*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from alder cover[a]	Adjusted r^2 for linear regression predicting diameter from alder cover[a]	p-value for linear regression predicting diameter from alder cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
4	69	6	25	$y = 5.276 - 0.026\,x$	0.07	0.02	37	$y = 5.121 - 0.015\,x$	0.26	0.00		
23	72	5	35	$y = 9.989 - 0.031\,x$	0.15	0.00	60	$y = 10.028 - 0.052\,x$	0.28	0.00		
31	72	11	40	$y = 5.103 + 0.008\,x$	0.00	0.45	30	$y = 5.622 - 0.015\,x$	0.01	0.02		
55	61	5	30	$y = 4.802 - 0.002\,x$	0.03	0.10	25	$y = 5.505 - 0.045\,x$	0.41	0.00	$y = 6.017\,e^{(-0.014 * x)}$	0.43
mean (s.e.)			33 (2)				38 (6)					

[a] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is Sitka alder cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (Sitka alder cover * Sitka alder modal height)/pine total height.

[c] General form of non-linear equation is $y = a\,e^{(b\,x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

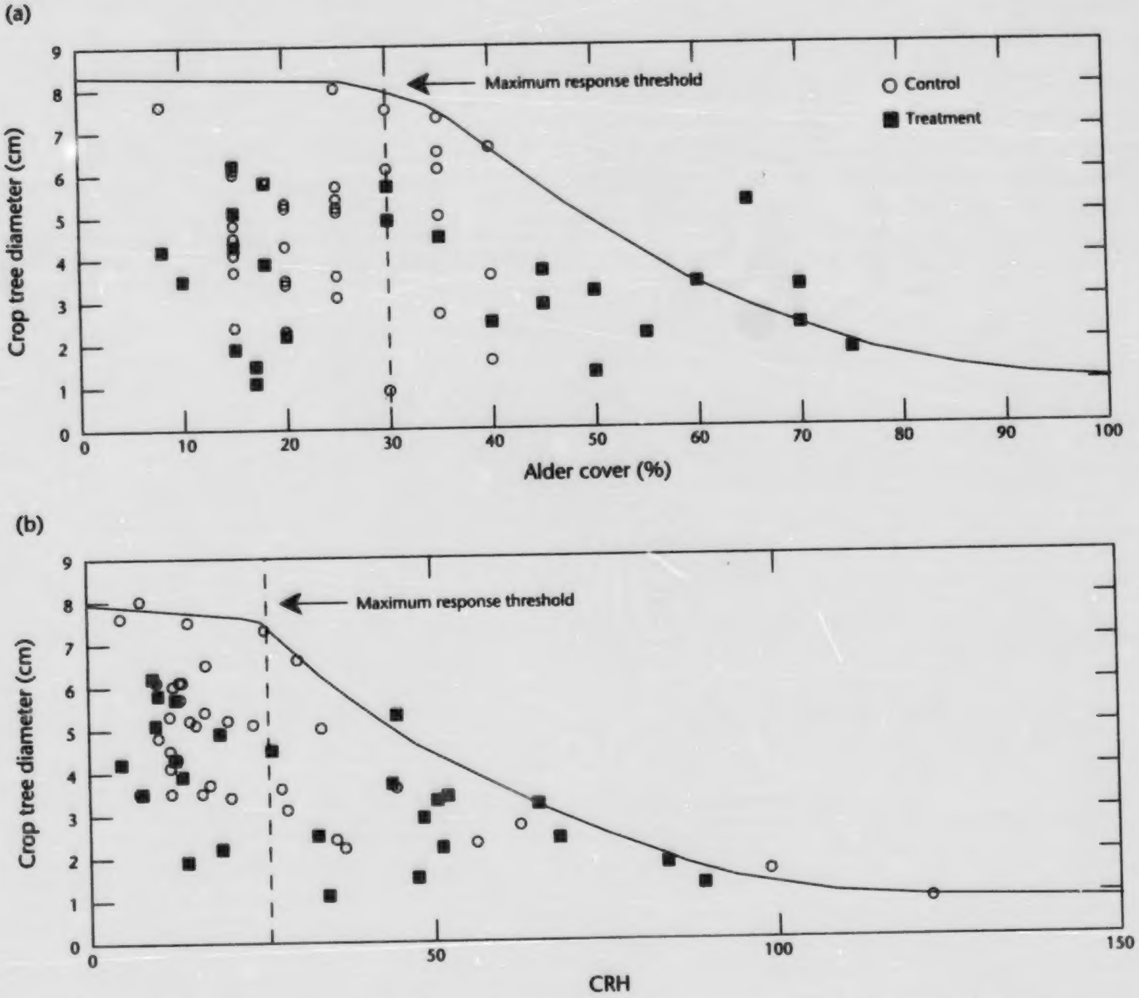


FIGURE 91 *Relationship between stem diameter of lodgepole pine growing amongst the Dry Alder Complex and (a) alder cover or (b) CRH, where CRH = (alder cover * alder modal height)/pine height. Data points include both treatment and control subplots for PROBE site 55 (n = 61). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

Here we discuss fifth-year responses of lodgepole pine and the *Dry Alder* Complex in the MS zone to manual cutting in August–September, and compare our results with manual cutting and glyphosate applications reported in other studies. The *Dry Alder* Complex is often sufficiently abundant 10 years after disturbance to give the impression that it is hindering the performance and/or free-growing status of lodgepole pine stands. Manual or chemical brushing treatments are applied in anticipation that they will relieve these constraints; however, our results suggest that alder is competing very little with pine on mesic sites and that there are minimal benefits to brushing this community.

Conifer Response

Five years after manual brushing, lodgepole pine survival was excellent (average 98%) in both the treatment and control. The 10–12-year-old seedlings (5–7 years old at the time of treatment) were healthy and gradually improving in vigour, regardless of whether alder had been manually cut. Simard (1990b) found that survival of lodgepole pine growing among the *Dry Alder* Complex stabilized within 3 years of planting, and high survival rates had also been anticipated among the well-established pine in our study (5–7 years old at brushing). However, pine had been established more or less concurrently with alder in our and Simard's studies, whereas data from one of our unreplicated treatments suggest that where pine are planted under an established alder canopy, survival may be improved by brushing (Mather and Simard 1998d; Appendix 1).

Lodgepole pine in our study were growing at adequate rates according to Vyse and Navratil (1985) and their growth was not improved by manual brushing. Pine on other mesic MS sites have demonstrated a similar lack of response to reductions in alder abundance (Simard 1990b; Simard, Heineman, and Youwe 1998), whereas on a submesic ICH Dry Alder site, modest increases in pine stem diameter occurred within 2 years of manual and chemical brushing and height increased significantly by year nine (Simard and Heineman 1996c). A more pronounced growth response may occur on mesic sites where the *Dry Alder* Complex was well established at the time pine seedlings were planted (Mather and Simard 1998d; Appendix 1). Manual and chemical brushing appear to result in similar pine seedling responses, in spite of having somewhat different effects on the vegetation community (Simard and Heineman 1996c).

Plant Community Response

The recovery of Sitka alder following manual cutting was variable across our three study sites, with the result that few of the treatment effects on vegetation were statistically significant. Alder height was reduced in the first-year assessment, but there were no further statistically significant effects on either its height or cover. Nonetheless, alder abundance had recovered to only about half of control levels after 3 years, and to about two-thirds of control levels after 5 years. Alder recovery rates were also variable among other studies. Simard (1990b) found that alder regained height and cover at similar rates to ours, but in two of our unreplicated manual treatments, recovery was more rapid (Mather and Simard 1998d, 1998e; Appendix 1). On other southern interior sites, however, alder recovered extremely slowly; in one study, crown volume of cut alder averaged less than 25% of the control after 4 years (Lloyd and Heineman 1994b) and in a second study, height and cover of alder were 33 and 13%, respectively, of control values after 9 years (Simard and Heineman 1996c).

First-year growth of alder sprouts averaged 33 cm in our study, which is similar to rates of 40–65 cm/yr reported for other sites in the southern interior (Haeussler et al. 1990; Simard 1990b; Mather and Simard 1997e, 1998d, 1998e; Appendix 1). Alder on our sites was cut between mid-August and mid-September, which, according to Lloyd and Heineman (1994b), should be as equally effective as cutting it at any other time. Vigorous, prolific sprouting occurred in one of our unreplicated manual treatments, where alder was young (4 years old) at the time of cutting (Mather and Simard 1998e; Appendix 1). We observed no relation between sprouting vigour and site type, but other sources report lower sprouting vigour on poor than on medium sites (Hauessler et al. 1990). The slow recovery of alder on a submesic site also suggests that soil water may limit sprout vigour (Simard and Heineman 1996c).

We do not yet have sufficient replication to report on the effects of foliar glyphosate; however, numerous studies have shown that Sitka alder is severely injured by a rate of 2.1 kg ai/ha (Boyd et al. 1985; Thompson 1989; Lloyd and Heineman 1994b; Simard and Heineman 1996c; Simard, Heineman, and Youwe 1998) and moderately to severely injured by a rate of 1.78 kg ai/ha (Thompson 1989; Simard and Heineman 1996c; Simard, Heineman, and Youwe 1998). The recommended window for brushing Sitka alder with glyphosate is May through October (Lloyd and Heineman 1994b), and efficacy is reportedly poorer on dry than on moist sites (Haeussler et al. 1990).

In some vegetation communities, removing overstorey tall shrubs or broadleaves can stimulate increases in the abundance of herb and low shrub layers; however, this did not occur in our study. Simard and Heineman (1996c) likewise found that manual cutting of the *Dry Alder* Complex had no effect on fireweed abundance. Chemical brushing, on the other hand, has moderately reduced fireweed abundance on dry alder sites for 1–3 years (Simard and Heineman 1996c; Simard, Heineman, and Youwe 1998; Mather and Simard 1998m).

Manual cutting of the *Dry Alder* Complex did not affect species richness or diversity in our study, which agrees with our manual cutting results for other complexes. Haeussler (1999) comments that conventional forest management practices have rarely reduced diversity or richness of vascular species during early forest succession.

Effects of the Plant Community on Resource Availability

The *Dry Alder* Complex is thought to compete with conifer seedlings mainly for light, and brushing is often applied with the objective of relieving this constraint. However, in our study, 20–30% Sitka alder cover was not competing strongly with established (5- to 7-year-old) lodgepole pine, and reducing alder abundance had no effect on survival, vigour, or growth. Alder distribution in the *Dry Alder* Complex tends to be clumpy rather than continuous, and most seedlings grow in the spaces between alder clumps where they are likely to experience only minor light limitations. Simard (1990b) found that even the maximum density of alder (2514 clumps/ha) allowed approximately 68% of full sunlight to reach the terminal bud of 1-year-old pine, and that removal of alder alone did not increase light availability to seedlings.

In the Simard (1990b) study, improvements in seedling growth were related to soil and air temperature as well as to light, and occurred when the entire herb layer was removed in addition to alder. Severe treatments that expose mineral soil are normally prescribed only where low soil temperatures are critically limiting to seedling growth, and tend to be applied as site preparation rather than brushing treatments. In southern interior British Columbia, the *Dry Alder* Complex is most common in biogeoclimatic zones with relatively moderate climates (e.g., MS, ICH, IDF), where low soil temperatures are not considered an important limiting factor. The focus of managing this complex may differ in other areas of the province with more severe climates.

Although pine on our mesic sites were not negatively affected by the presence of alder, competition for soil water by the *Dry Alder* Complex may reduce growth on drier sites. For instance, on a submesic MS site, Simard and Heineman (1996c) attributed increases in lodgepole pine diameter and height to a reduction in competition for soil resources rather than for light. Pinegrass is often abundant in the understorey on submesic or drier dry alder sites, and its presence is likely to contribute to competition for soil water (e.g., Petersen and Maxwell 1987; Nicholson 1989). On sites where grass is abundant, water competition would likely be ameliorated more by reducing grass than by reducing alder cover.

The ability of Sitka alder to fix nitrogen and generally improve site quality is well known, and brushing treatments that reduce alder abundance below the threshold for relieving competition may unnecessarily affect long-term site productivity and short-term availability of nitrogen for seedlings. Simard (1997, unpublished data) observed that levels of available nitrogen in mineral soil were significantly reduced 10 years after complete removal of alder. Brockley and Sanborn (pers. comm., 1999) likewise found that foliar nitrogen concentrations in pine were reduced where neighbouring alder had been removed 3 years earlier.

Competition Thresholds

The competition thresholds for stem diameter of 5- to 11-year-old lodgepole pine averaged 33% for Sitka alder cover and 38 for CRH. Above the thresholds, interspecific competition appeared to be the most important factor limiting tree growth, setting the upper limit for pine stem diameter. However, only a small proportion (12–20%) of trees were growing in alder neighbourhoods above the 33% cover and 38 CRH thresholds (ranges in localized alder cover and CRH were 0–80% and 0–200, respectively), suggesting that competition was not constraining most trees in the plantations. Most lodgepole pine above the thresholds were control trees growing inside dense alder clumps. Below the thresholds, variability in stem diameter was high among both treated and control pines, likely due to certain factors (e.g., genetics, microenvironment, and other biotic factors) overriding the competitive effects.

Lowering alder cover below the thresholds theoretically reduced competitive constraints and created conditions for greater pine growth. Brushing was successful at ensuring that 80–90% of treated trees fell below the thresholds. However, 75–80% of control trees also occurred below the thresholds, suggesting that most of the untreated plantation was not suppressed by alder competition. In addition, brushing had no effect on either mean diameter or diameter distributions of lodgepole pine. Most treated trees continued to grow at levels lower than 80% of the maximum growth potential of the sites. The lack of response to brushing, the low proportion of trees that naturally occurred above the competition thresholds, and the poor regressions relating pine diameter to competition indices together suggest that interspecific competition between pine and alder was of low importance and intensity in our plantations. If brushing is carried out, we think it should focus only on the small proportion of trees growing in alder clumps above the competition thresholds. Our studies show that most of these suppressed trees occupy the lower-diameter classes in moderately high-density pine stands, however, and their release may not result in increased stand productivity.

The 33% Sitka alder cover threshold for our 5- to 11-year-old lodgepole pine plantations fell within the range in alder cover thresholds (range 10–40%, average 33%) identified by Simard (1990b) for 6- to 10-year-old lodgepole pine on similar dry alder mesic, MS sites. Our cover threshold also agrees with results of experimental studies conducted on similar sites. For example, Simard (1990b) found that reductions in Sitka alder from approximately 35% (2514 clumps/ha) to 26, 17, 8, and 0% cover had no effect on 3-year-old pine diameter on a mesic MSxk site. After 10 years, lodgepole pine diameter still did not differ between no (35% cover) or partial (26, 17, and 8% cover) alder removals, but averaged 1 cm larger (5.8 cm versus 4.8 cm) where all alder had been removed (0% cover) (Simard, unpublished data). However, complete alder removal also corresponded with significant reductions in available nitrogen, from 7.0 ppm NH_4-N in the 35% alder cover treatment to 3.0 ppm NH_4-N where all alder had been removed ($p = 0.10$) (Simard, unpublished data). Similarly, Brockley and Sanborn (unpublished data) found on a mesic SBS site that Sitka alder reductions from 40 to 20 or 0% cover had no effect on 3-year lodgepole pine diameter, but that complete alder removal significantly reduced pine foliar N concentrations ($p<0.05$). At the same time, retention of 10% alder cover resulted in significantly greater pine diameter than the other treatments ($p<0.05$). The results from these two studies suggest that complete alder removal is not desirable in terms of nutrient cycling or productivity. Partial alder removal, which characterizes operational brushing, has no effect on pine growth, and complete removals are neither operationally feasible nor ecologically desirable.

In yet another study, Simard, Heineman, and Youwe (1998) found no effect of Sitka alder reductions from 27 to 2% cover on 9-year lodgepole pine growth on a mesic site in the MSdm2 variant. Alder cover was already below the thresholds identified in our study and by Simard (1990b), and did not pose a sufficient competitive threat to pine to generate a brushing response. In contrast, Simard and Heineman (1996c) found that alder cover reductions from 22 to 15–18% cover resulted in a 1-cm increase in pine diameter (6.7 cm versus 7.7 cm) after 9 years. That study was conducted on a drier, submesic site in the ICHmk1 variant, however, and growing-season water deficits may have been exacerbated by higher alder densities.

Effectiveness of Treatments at Meeting Management Objectives

A primary objective of brushing the *Dry Alder* Complex is to improve seedling performance; however, our results show clearly that manual brushing was not required to ensure good survival and growth of lodgepole pine seedlings that were 5–7 years old at the time of treatment. A common second objective of brushing this community is to help seedlings meet free-growing requirements at the earliest possible date, but again, the treatment proved unnecessary. Manual cutting reduced the time to reach free-growing by only 1 year.

For our MS study sites, the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000) specify target stocking of 1200 (minimum 700) well-spaced conifer stems/ha, and that 12–15 years after establishment, pine must be at least 1.4 m tall and 100% as tall as neighbouring vegetation. In our study, pine (on average) met the minimum height requirement at the time of brushing, and they were above the height of surrounding vegetation immediately after cutting. However, regulations specified that seedlings could not be classified as free-growing until a minimum 2-year interval had passed. Meanwhile, control pine were gaining on alder in height, and also met the conifer:vegetation height ratio requirement within 3 years of brushing (Figure 92). Therefore, on average, treated seedlings met free-growing criteria when they were 7–9 years old and control seedlings when they were 8–10 years old, which is below the early free-growing assessment age for the MS zone. This interpretation of the treatment effects is supported by fifth-year silviculture survey data, which showed an average 883 stems/ha were free-growing according to the old guidelines (B.C. Ministry of Forests 1995a).

Other studies also found that untreated pine naturally outgrew alder within a few years of manual cutting, even when pine was short (<1 m) at the time of treatment (Simard and Heineman 1996c; Simard, Heineman, and Youwe 1998). In our study, qualitative observations suggest that the size of pine at the time of treatment was of little consequence to the effectiveness of the treatment at allowing pine to grow above the height of alder. Pine typically grow at a similar rate to or faster than alder sprouts, and at least twice as fast as maturing untreated alder plants. Although we do not have sufficient replication of sites to present results for spruce growing among the *Dry Alder* Complex, it may be less likely to outgrow untreated alder within the free-growing window because of its generally slower rates of height growth.

Sites occupied by the *Dry Alder* Complex frequently occur in areas that are managed for range as well as silviculture. Chemical brushing, in particular, can negatively affect forage production (Simard, Heineman, and Youwe 1998), and it is important that treatments not be applied unnecessarily. Our results and those of others (e.g., Simard 1990b; Simard, Heineman, and Youwe 1998) suggest that brushing alder on mesic sites was not justified because it did not improve pine performance or help meet free-growing criteria. Silviculture and range objectives are most likely to conflict on drier sites where grass is common in the understorey and may be competing with conifer seedlings for soil water.

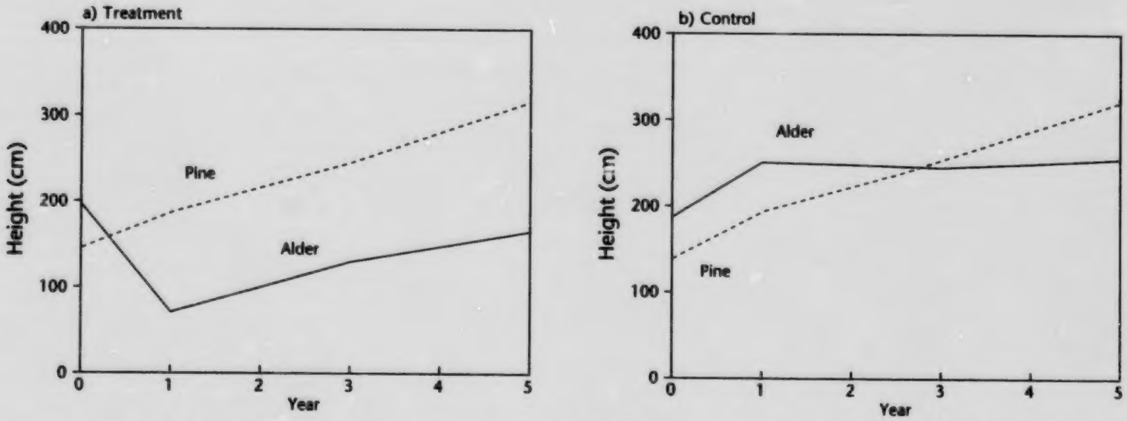


FIGURE 92 *Comparison of average lodgepole pine and alder height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the MS* Dry Alder Complex. *Values for years 2 and 4 were interpolated from actual data. Treated pine were taller than alder in the first year after manual cutting, while control pine outgrew the canopy after 3 years.*

CONCLUSIONS

We found that manual cutting reduced alder abundance, but had no effect on survival, growth, or vigour of established (5–7 years old at the time of treatment) lodgepole pine. Neither was treatment predicted to be necessary for seedlings to meet free-growing requirements (B.C. Ministry of Forests 2000). Although brushing initially improved the competitive status of pine stands, untreated pine naturally outgrew alder within 3 years of the brushing date. Some studies report small increases in conifer growth following alder brushing, but they were usually associated with complete experimental herb removal, or colder or drier site conditions. Most pine in our study were growing in alder neighbourhoods that were below the identified competition thresholds (33% alder cover and CRH 38), suggesting that very few, even in the control, were suffering from the effects of competition. The few suppressed trees tended to be growing right inside alder clumps, and their release is likely to have little effect on the ultimate success and productivity of the plantation.

1. Reducing alder abundance did not improve survival or vigour of lodgepole pine that were 5–7 years old at the time of manual cutting. Pine seedlings can be expected to perform well among clumpy, moderately abundant alder (<33% average cover) without brushing.
2. On our study sites, brushing the *Dry Alder* Complex is predicted to reduce the time for pine seedlings to meet free-growing requirements (B.C. Ministry of Forests 2000) by only 1 year. Unless alder is well-established or particularly abundant, brushing will not be required for established pine on mesic sites to meet free-growing requirements within the assessment window. Further study is required to determine whether spruce seedlings growing among alder require brushing to meet free-growing.
3. Manual cutting may effectively be applied to the *Dry Alder* Complex throughout the growing season because sprouting vigour does not appear to be related to treatment date. It has less potential to reduce cattle forage than chemical brushing, but may impede cattle access.
4. Other studies show that glyphosate applied at 1.78–2.10 kg ai/ha from May through October will result in severe injury to alder. Lower rates will preserve some alder cover, which has positive implications for short- and long-term site productivity.
5. Competition thresholds for pine diameter growth were identified at 33% Sitka alder cover and 38 CRH. Most pine in both the treatment and control were growing in alder neighbourhoods below these thresholds, and brushing did not improve average pine growth. Pine growing among the *Dry Alder* Complex are unlikely to be experiencing significant competition as long as average alder cover is below 33%.
6. Our results showed that manual cutting had no effect on the richness or diversity of vascular plant species associated with the *Dry Alder* Complex.

SECTION 9

Wet Alder Complex

ABSTRACT

Manual cutting significantly reduced the abundance of alder and overall vegetation from control levels, but 3 years after treatment there were no improvements in survival, stem diameter, diameter increment, height, or leader length of 7- to 9-year-old Engelmann spruce seedlings (4–7 years old at the time of treatment). However, height:diameter ratio had become significantly lower in the treatment than in the control (46.4 versus 55.5), suggesting that seedlings were becoming sturdier. Cutting damage at one of the sites initially reduced seedling vigour in the treatment. Prior to cutting, alder was 257.7 cm tall with 32.3% cover; 1 year after treatment it was 81.3 cm tall with 7.3% cover, and after 3 years it was 146.3 cm tall with 17.4% cover. Alder stumps sprouted, but the sprouts grew an average of only 7 cm in the first year after cutting and an average of 36.5 cm/yr in the 2 following years. Herb abundance did not increase significantly following removal of the alder canopy. Species richness decreased in the treatment relative to the control in the first year after manual cutting, but was the same as the control by year 3. Diversity was unaffected. Competition thresholds for spruce stem diameter averaged 37% Sitka alder cover and 107 CRH. Reducing alder abundance below these thresholds should improve conditions for spruce growth. Manual brushing of the *Wet Alder* Complex on these study sites is predicted to assist seedlings in meeting the minimum height and conifer:vegetation height ratio requirements for free-growing (B.C. Ministry of Forests 2000), but is unlikely to help meet the stocking requirement.

Description of the *Wet Alder* Complex

The *Wet Alder* Complex is dominated by Sitka alder (*Alnus viridis* ssp. *sinuata*) in the southern interior, but often includes mountain alder (*Alnus incana* ssp. *tenuifolia*) and low shrubs such as thimbleberry (*Rubus parviflorus*) and black twinberry (*Lonicera involucrata*) (Figure 93). In southern interior British Columbia, herb species commonly associated with this complex are lady fern (*Athyrium filix-femina*), bluejoint (*Calamagrostis canadensis*), spiny wood fern (*Dryopteris expansa*), bracken (*Pteridium aquilinum*), and fireweed (*Epilobium angustifolium*) (Kimmins and Comeau 1990; Boateng and Comeau 1997c). The *Wet Alder* Complex occurs predominantly on rich, wet sites, and is common in seepage areas. In southern interior British Columbia, it is most often found in the ESSF and ICH biogeoclimatic zones, and is extensive in the transition area between these zones. It also has limited occurrence in the MS zone (Kimmins and Comeau 1990; Boateng and Comeau 1997c).

Development of the *Wet Alder* Complex

The *Wet Alder* Complex develops relatively quickly following harvest; within 3–10 years it can form a continuous thicket that drastically reduces the amount of solar radiation reaching conifer seedlings and the soil surface. The rich, moist site conditions where alder thrives are also conducive to abundant herb growth, particularly in areas not fully occupied by shrubs.

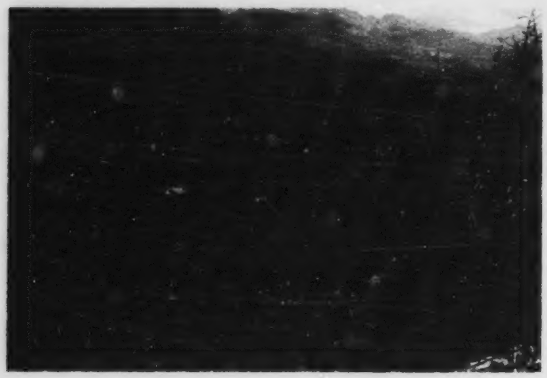


FIGURE 93 *The Wet Alder Complex prior to manual cutting at Beaverfoot River (Site 104) in the ICHmk1 variant in the Golden Forest District. Photo credit: JMJ Holdings Inc.*

Sitka and mountain alder are common in the understorey of southern interior forests, and following harvesting, tend to spread vegetatively in response to increased light availability (Haeussler et al. 1990). The *Wet Alder* Complex is often well-developed in gaps and along the borders of spruce–subalpine fir forest, and these swales spread into openings created by logging. This is particularly common following winter-logging, which inflicts little damage on existing alder clumps (Boateng and Comeau 1997c). However, summer-logging and low-impact MSP can also promote development of this complex by exposing mineral soil and stimulating root sprouting (Haeussler et al. 1990). In addition to vegetative reproduction, both Sitka and mountain alder produce abundant airborne seed and readily colonize disturbed areas, especially where mineral soil is exposed (Haeussler et al. 1990).

Sitka alder is more widely distributed and common than mountain alder in the southern interior (D. Lloyd, pers. comm., 2000) and the two species have slightly different growth requirements. Mountain alder has a slightly higher requirement for soil water than Sitka alder; it is found most often on wet sites, whereas Sitka alder has its best growth on moist, but reasonably well-drained, sites (Haeussler et al. 1990). Both species have high nutritional requirements, but growth of Sitka alder, at least, is independent of nitrogen levels (Harrington and Deal 1982). Under favourable conditions, Sitka alder grows to about 5 m tall, and mountain alder to 10 m tall (Parish et al. 1996).

Thimbleberry and black twinberry are common low shrubs in the *Wet Alder* Complex, and like alder, they also increase in height and density in response to canopy removal. Both may reach heights of 2.5 m. Thimbleberry is rhizomatous, and spreads readily by vegetative means (Haeussler et al. 1990). Disturbance of the forest floor, such as that which occurs during summer-logging, is also likely to stimulate ingrowth of these seed-banking shrubs.

Most of the herbs associated with the *Wet Alder* Complex are rhizomatous. Lady fern, bracken, fireweed, and bluejoint have varying levels of shade tolerance, but all express their most vigorous growth in open conditions (Klinka et al. 1989; Haeussler et al. 1990). In addition, fireweed and bluejoint have light, wind-borne seeds that make them aggressive invaders of freshly disturbed sites. Under the moist, rich site conditions where the *Wet Alder* Complex commonly develops, these herbs can reach heights of 2–3 m (Parish et al. 1996; Boateng and Comeau 1997c).

Interactions with Conifer Seedlings

The presence of some alder can benefit conifers by increasing the availability of nitrogen and by improving long-term site productivity. In British Columbia, Sitka alder is estimated to fix from 1.5 to 35 kg N/ha/yr (Binkley 1981, 1982; Sachs and Comeau 1991). Fixation rates are thought to be lower in the southern interior of the province (1.5–8 kg/ha) than on the coast because of the shorter growing season, and because alder cover tends to be patchy rather than continuous (Sachs and Comeau 1991). There is also evidence that alder and conifer seedlings can be linked by the same ectomycorrhizal fungi, allowing for direct transfer of fixed nitrogen from the alder to the conifer (Arnebrant et al. 1993).

When abundant, the *Wet Alder* Complex can negatively affect seedling performance by competing for light and soil resources, by inhibiting soil and air warming, and by causing physical damage through snow- and vegetation-press. Many species of wildlife use this community as cover, and browse damage to seedlings may also be extensive (e.g., Sullivan 1985; Stathers et al. 1994). Thorpe (1996) notes that, in northern British Columbia, the *Wet Alder* Complex often develops on sites where poor seedling performance is related primarily to the effects of cold, wet, fine-textured soils on seedling root development, rather than to vegetation competition. These comments likely also apply to the *Wet Alder* Complex in the harsh environment of high-elevation ESSF sites in the southern interior.

Importance to Wildlife and Range

Few of the individual plant species associated with the *Wet Alder* Complex are of high importance to wildlife, but there are several low to moderately important species. Some birds feed on alder seeds, and small and large mammals may eat the twigs and foliage (Healy and Gill 1974). Catkins provide food for squirrels (Harestad 1983, cited by Haeussler et al. 1990). Sitka alder clumps provide cover for ungulates, and also for small mammals such as showshoe hares, red squirrels, and voles (Haeussler et al. 1990). Recent work in north-central British Columbia has also shown that grizzly bears utilize small alder swales for food and bedding down (C. DeLong, pers. comm., 2000). Thimbleberry and black twinberry both produce berries that are eaten by a variety of mammals and birds (Haeussler et al. 1990). Of the herbs associated with this vegetation community, lady fern is probably the most important to wildlife, providing winter food for various ungulates and early summer food for black and grizzly bears (Haeussler et al. 1990).

Fireweed and bluejoint are preferred forage for sheep, whereas alder, black twinberry, and bracken are grazed minimally or inconsistently (Newsome 1996). Cattle have a moderate preference for bluejoint and a low preference for fireweed (McLean 1979). Bracken may be toxic to cattle and sheep if it is grazed for long periods (Ferguson and Boyd 1988).

Common Brushing Treatments in the *Wet Alder* Complex

Boateng and Comeau (1997c) comment that a well-developed *Wet Alder* Complex is best controlled with high-impact site preparation that damages or destroys the root system, but, even so, brushing is usually also required. Seeding with grasses and legumes following mechanical site preparation can reduce the re-invasion of alder, and may also reduce the competitive ability of the herb and low shrub layer (Stathers et al. 1994). However, there are some concerns that severe site preparation treatments and seeding may have negative effects on soils and plant communities. Common brushing treatments applied to the *Wet Alder* Complex in British Columbia are, in order of importance, manual cutting, foliar glyphosate spray, and cut stump glyphosate application (Table 86). Sheep have little impact on tall shrub communities, but they can be effective as a follow-up treatment to reduce the abundance of herbs.

TABLE 86 *Common brushing treatments applied to the Wet Alder Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Reduce light competition 2. Reduce competition for soil resources 3. Reduce physical damage 4. Increase soil warming	Anytime[b]	≥ 2[c]	1. Brush saw 2. Power saw	$538 $538	1. Vigorous sprouting 2. Treatment damage to seedlings 3. Difficult planter access
Glyphosate (1.4–2.1 kg ai/ha)	1. Reduce light competition 2. Reduce competition for soil resources 3. Increase soil warming	Mid-June to October[b,d]	1	1. Backpack sprayer 2. Fixed-wing plane or helicopter (aerial)	$695 $311	1. Cannot apply near waterways 2. Variable efficacy for understorey because of dense canopy 3. Seedling damage from dead alder stems 4. Difficulty obtaining herbicide permits
Cut stump–glyphosate (10% soln.)[b]	1. Reduce light competition 2. Reduce competition for soil resources 3. Reduce physical damage 4. Increase soil warming	Unknown	1	1. Power saw and backpack sprayer or squirt bottle	Unknown	1. Time consuming 2. Difficulty obtaining herbicide permits

[a] Based on average costs for the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)
[b] Lloyd and Heineman (1994b)
[c] Boateng and Comeau (1997c)
[d] Boyd et al. (1985)

Manual Cutting

Engelmann spruce in the ESSF

This section summarizes third-year responses of Engelmann spruce seedlings and the *Wet Alder* Complex in the ESSF zone to manual cutting (n = 3). Seedlings were 4–6 years old at the time of treatment. No attempt was made to differentiate between Sitka alder and mountain alder in this study.

Description of the study sites and treatments

Two of the three study sites are located in the Kamloops Forest Region; the Miner Creek site is 30 km west of Merritt in the Moist Warm ESSF subzone (ESSFmw) of the Merritt Forest District, and the Palmer Creek site is 16 km west of Salmon Arm in the Thompson Dry Cold ESSF variant (ESSFdc2) of the Salmon Arm District. A third site at Beaverfoot River is in the Nelson Forest Region, in the Kootenay Moist Cool ICH variant (ICHmk1) of the Golden Forest District. The ICH site was analyzed along with the two ESSF sites because of its physiographic and vegetation similarities. The three sites have similar slopes (35–45%) and aspects (easterly), and elevations range from 1350 to 1500 m. Two of the sites are subhygric and one is mesic and all are in lower or mid-lower slope positions. Soils are silty- or loamy-textured Brunisols and Luvisols.

Histories for these sites are similar (Table 87). All are backlog sites that were clearcut harvested, and two of the sites were broadcast burned several years after logging. PROBE was initiated 22 years after prescribed burning on two sites, and 13 years after grass seeding on the third site. One site had regenerated naturally to Engelmann spruce, and the other two sites were planted to that species. Seedlings were 4–6 years old when pre-treatment measurements were carried out.

Prior to manual cutting, alder on the three sites ranged from 2.1 to 3.2 m tall, with mean cover values ranging from 27 to 42%. Mean Engelmann spruce height on the three sites ranged from 39 to 111 cm and the majority of seedlings were overtopped by surrounding vegetation. Distribution of alder was variable and clumpy, but more than 75% of seedlings appeared to be in need of release. Alder was of good or excellent vigour on all three sites, and was increasing in height by an average of 27 cm/yr. Fireweed was ubiquitous on the three sites, and mean cover ranged from 14 to 26%. Willow was common enough to be considered a target species at the Beaverfoot River site, and contributed to overall shrub cover. On average, the herb layer occupied 44% cover and was 87 cm tall on the three sites. At the time of treatment, total conifer stocking ranged from approximately 1900–5800 stems/ha. Well-spaced stocking was 1100–1200 stems/ha on two sites, but was only 294 stems/ha on the Beaverfoot River site.

Alder was cut near the root collar using motorized brush saws or power saws at all three sites (Table 88). At two sites, brushing was carried out in August. The third site was brushed 2 years in a row in late June.

Conifer response

Survival and vigour Three years after manual cutting, there was no significant difference in the average survival of 7- to 9-year-old spruce seedlings (4–6 years old at the time of treatment) between the control and manual cutting treatment (average 93%, p>0.10) (Table 89). Cutting damage at the Beaverfoot River site was responsible for three-quarters of the mortality of treated seedlings, and the low mortality in the control was attributed to competing vegetation.

Cutting damage caused the percentage of poor-vigour seedlings to increase in the treatment relative to the control in the first year after treatment, and the effect was still noticeable after 3 years (Figure 94). Prior to treatment, 29% of seedlings were of poor vigour. Three years later, 28% of seedlings were still of poor vigour in the treatment, compared to 16% in the control. During the same period, however, the vigour of many seedlings improved from moderate to good. Within 3 years of treatment, the proportion of seedlings of good vigour increased from 26 to 53% in the treatment and from 23 to 43% in the control.

Growth Three years after manual cutting, there were no significant differences in seedling stem diameter, diameter increment, height, or leader length between the treatment and the control (p>0.10) (Table 89). Prior to treatment, the 4- to 6-year-old spruce seedlings averaged 75.0 cm tall and

TABLE 87 *Characteristics and history of the three replicate study sites where the ESSF Wet Alder Complex was manually cut in Engelmann spruce plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Miner Creek PROBE 24 Merritt District	ESSFmw 01 (mesic)	1350	NE 35%	Brunisol/ sandy loam	Clearcut 1978 Grass seeded 1979	14	13	5	N	n/a	5	75 (21)	Alder cover: 42 (23) Alder height: 316 (46) Fireweed cover: 18 (14) Fireweed height: 145 (32)	5814	1200
Palmer Creek PROBE 57 Salmon Arm District	ESSFdc2 07 (subhygric)	1475	SE 35%	Luvisol/ silty clay loam	Clearcut 1952-62 Burned 1973	33	22	4	P 1974/75 P 1991	PSB 313A	4	39 (10)	Alder cover: 28 (26) Alder height: 214 (10) Fireweed cover: 26 (12) Fireweed height: 94 (21)	1848	1081
Beaverfoot River PROBE 104 Golden District	ICHmk1 06 (subhygric)	1500	E 45%	Brunisol/ silt	Clearcut 1964 Burned 1970	28	22	16	P 1974 P 1986	BR	6	111 (57)	Alder cover: 27 (17) Alder height: 243 (87) Willow cover: 9 (10) Willow height: 248 (146) Fireweed cover: 14 (11) Fireweed height: 116 (23)	1889	294

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting

[b] Origin: P = planted; N = natural regeneration

[c] Age refers to the number of years since planting

[d] Values are means and one standard deviation (in parentheses)

TABLE 88 *A description of manual cutting treatments applied to the three replicate study sites to release Engelmann spruce seedlings growing in the ESSF Wet Alder Complex*

Site	Initial treatment date	Treatment radius	Treatment tool	Repeat treatment
Miner Creek	August 1992	Variable to enable free-growing	Power saw	None
Palmer Creek	August 1996	1.0 m	Motorized brush saw	None
Beaverfoot River	June 24, 1993	Wildlife species were retained and other veg. >50 cm was cut	Motorized brush saw	June 28, 1994

TABLE 89 *Survival and growth responses of Engelmann spruce seedlings to manual cutting in the ESSF Wet Alder Complex*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	90	100	5.237	0.30
3 yr post-treatment	87	99	6.548	0.32
Stem diameter (cm)				
Pre-treatment	1.67	1.29	0.344	0.52
1 yr post-treatment	1.89	1.61	0.310	0.59
3 yr post-treatment	2.56	1.88	0.407	0.36
Diameter increment (cm)				
1 yr post-treatment	0.35	0.31	0.037	0.56
3 yr post-treatment	0.34	0.15	0.073	0.22
Height (cm)				
Pre-treatment	83.4	66.5	10.423	0.37
1 yr post-treatment	87.6	81.0	9.757	0.68
3 yr post-treatment	114.1	103.6	15.252	0.67
Leader length (cm)				
Pre-treatment	10.5	8.2	0.921	0.22
1 yr post-treatment	9.5	10.2	1.749	0.78
3 yr post-treatment	11.4	10.1	1.391	0.57
Height:diameter ratio				
Pre-treatment	53.9	52.9	3.495	0.86
1 yr post-treatment	49.2	51.1	1.722	0.52
3 yr post-treatment	46.4	55.5	1.518	0.05*

p-value denoted with "*" is significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

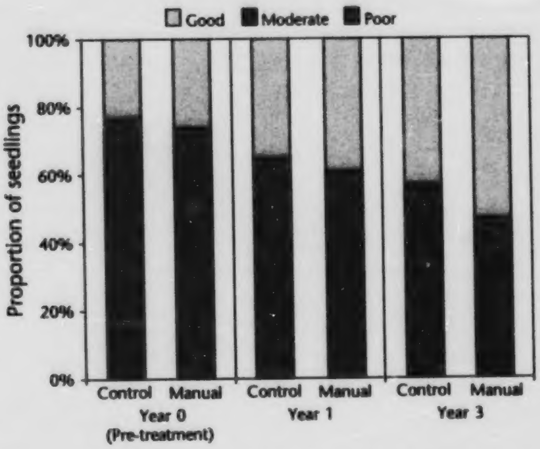


FIGURE 94 *Comparison of Engelmann spruce vigour between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF Wet Alder Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

were growing at 9.4 cm/yr. Three years later, when seedlings were 7–9 years old, they averaged 108.9 cm tall and were growing at 10.8 cm/yr. Average stem diameter was 1.48 cm prior to treatment, and it was 2.22 cm 3 years later. Although differences in height and stem diameter were not significant by year 3, the height:diameter ratio was significantly lower in the treatment than in the control (46.4 versus 55.5, p = 0.05), suggesting that seedlings were becoming sturdier as a result of manual cutting.

Standardized diameter distributions for spruce show that there was more variability above than below the mean prior to treatment (Figure 95). In other words, a few trees had considerably larger than average diameters, and many trees had slightly smaller than average diameters. The diameter distributions became more normal between the pre-treatment and third-year assessments, but remained similar in the treatment and the control. This agrees with ANOVA results that manual cutting of the *Wet Alder* Complex did not improve spruce diameter growth. The standardized height distributions indicate that there were more trees in the -1 class in the control than in the treatment prior to treatment, but this trend became slightly less pronounced following treatment (Figure 96). This suggests that the status of treated trees was not improved relative to those in the control, and is consistent with ANOVA results.

Competitive status Manual cutting of the *Wet Alder* Complex resulted in an immediate reduction in the degree of overtopping experienced by spruce seedlings, and the effect persisted through year 3 (Figure 97). Prior to treatment, only 5% of seedlings were free of surrounding vegetation. One and 3 years after cutting, 41% of treated seedlings were free of vegetation compared to 10% of control seedlings. The proportion of overtopped seedlings in the treatment was 60% prior to treatment, decreasing to 28% after 1 year, and then increasing to 40% by year 3. In comparison, 81% of control seedlings were overtopped prior to treatment, and the proportion decreased to 67% in year 1 and 69% in year 3.

Plant community response

Abundance Manual cutting caused a large reduction in the abundance of alder, which, prior to treatment, had a mean height of 257.7 cm and a mean cover of 32.3% (Table 90, Figures 98 and 99). One year after cutting, alder in manually cut plots was only 81.3 cm tall, with 7.3% cover. This represented a 75% reduction from control alder height (p = 0.09) and a 67% reduction from control alder cover (p = 0.04). After 3 years, manually cut alder had recovered to 17.4% cover (p = 0.05) and 146.3 cm height (p = 0.01). Alder in the control gradually increased in abundance to 45.1% cover and a height of 266.5 cm during the 3-year monitoring period (Figure 100).

Manual cutting also had a significant effect on overall shrub height and cover in the *Wet Alder* Complex, and although it was less dramatic than the effect on alder alone, it also persisted through year 3. Mean shrub cover was approximately 54.6% prior to treatment, and the shrub layer had a mean height of 233.9 cm. Three years after cutting, shrub cover was 45.6% in the cutting treatment, compared to 62.3% in the control (p = 0.07). In the same assessment, mean height of the shrub layer was 134.3 cm in the cutting treatment, compared to 252.2 cm in the control (p = 0.02). The effects of cutting on overall vegetation height mirrored those on alder and persisted through year 3, but the effects on overall cover were of a smaller magnitude and were significant for 1 year only.

Fireweed was also a target species, with mean pre-treatment cover and height of 19.5% and 118.1 cm, respectively. Neither cover nor height of fireweed was affected by manual cutting of the *Wet Alder* Complex (p>0.10). The herb layer was also unaffected by treatment (p>0.10).

Sprouting Although 72% of alder stumps sprouted in the first year after cutting, they averaged only four sprouts per stump and their growth was not vigorous. Average sprout length 1 year after cutting was 7 cm (Table 91). By year 3, the proportion of stumps with sprouts had dropped to 58%, but there continued to be an average of four sprouts per stump. Sprouts grew an average of 33 cm/yr between the first- and third-year assessments, and were 73 cm tall by year 3.

Richness and diversity of individual species and structural vegetation groups Within 1 year of applying manual cutting to the *Wet Alder* Complex, there was a significant difference in species richness but not species diversity; however, the difference disappeared by year 3 (Table 92). Prior to cutting, there were 44 species in the control and 40 species in the treatment, but the difference was not statistically significant (p>0.10). One year later, even though the means had changed very little (44 species in the control versus 39 species in the treatment), the difference was significant (p = 0.08).

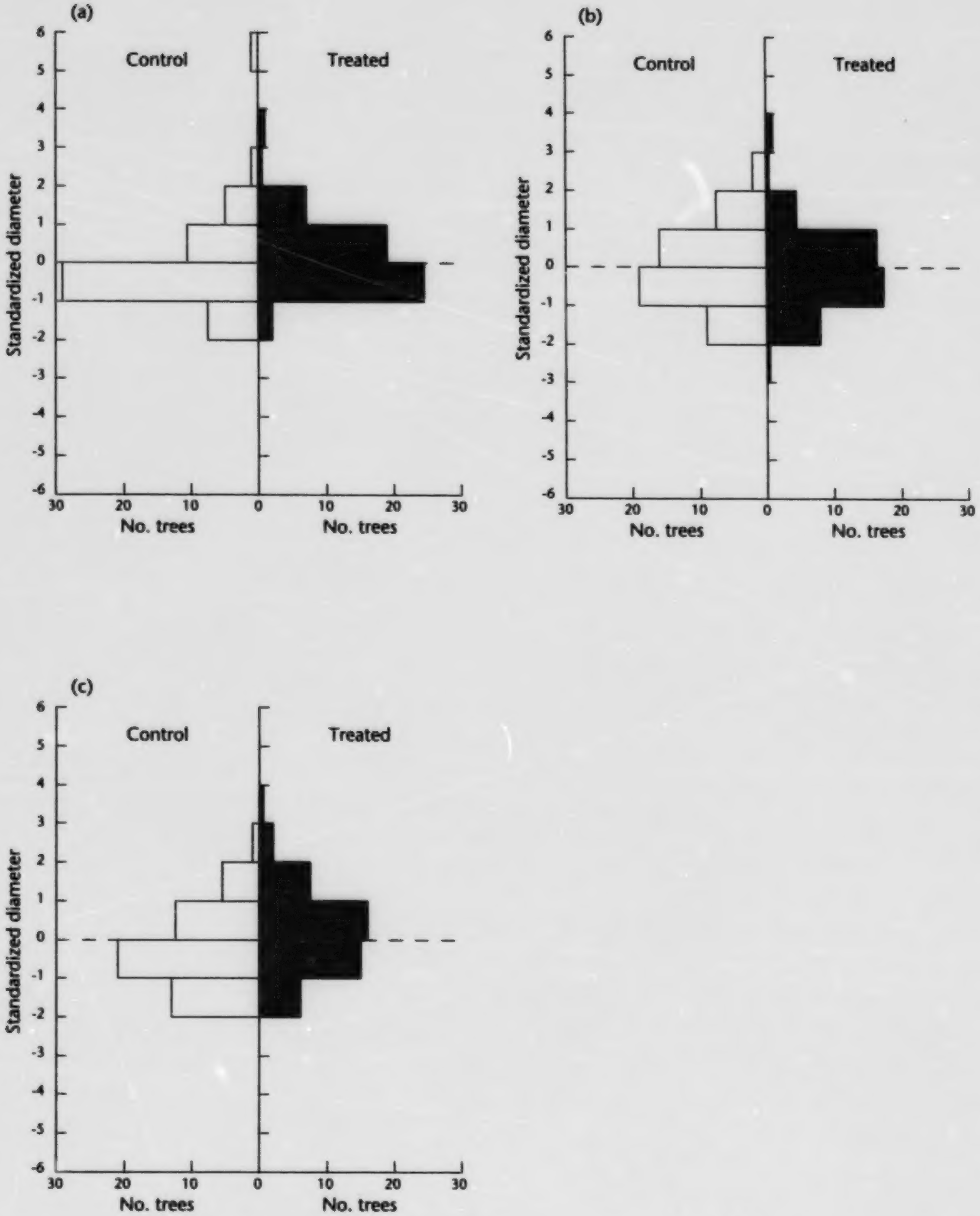


FIGURE 95 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Engelmann spruce in the ESSF Wet Alder Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

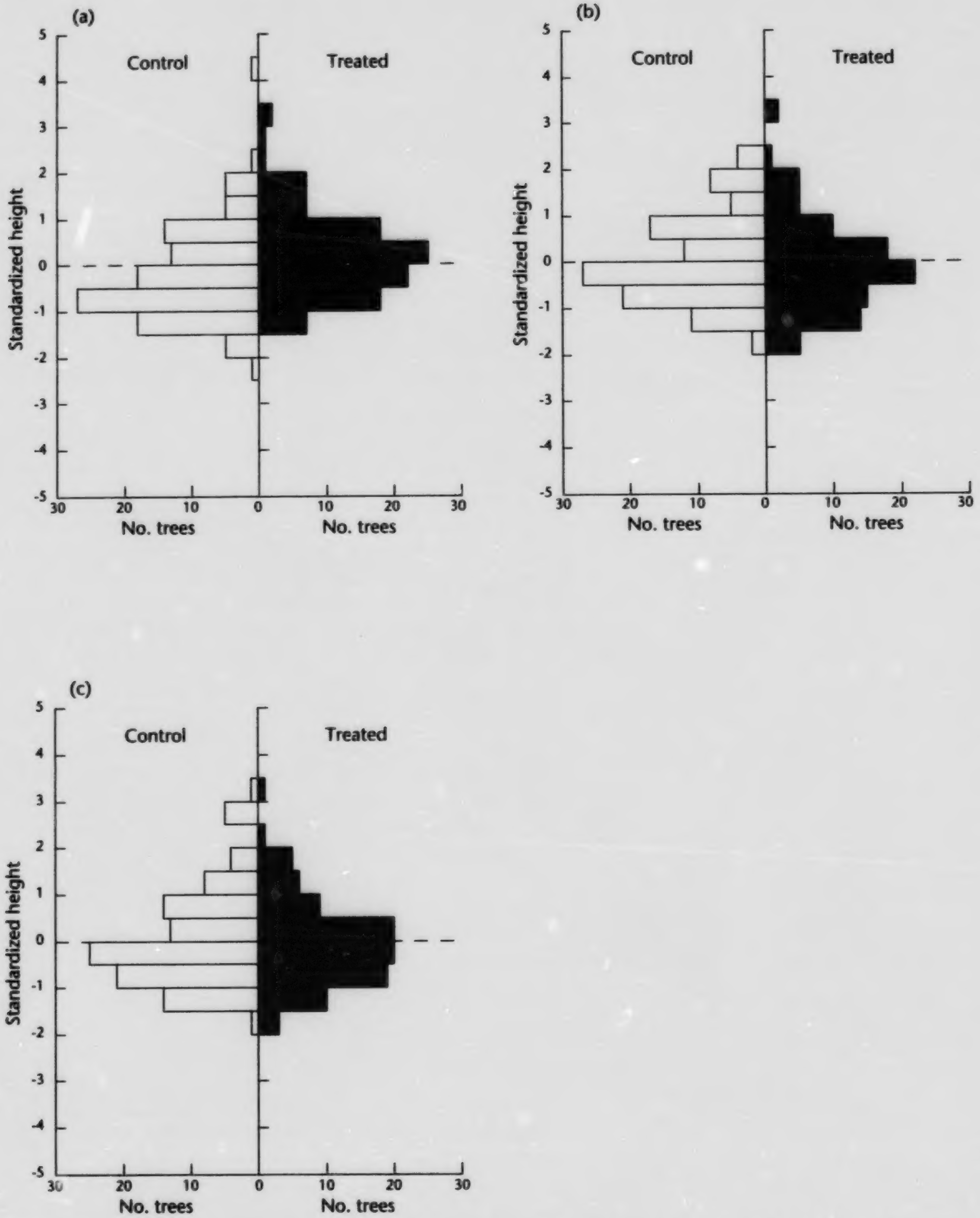


FIGURE 96 *Frequency of control and treated trees in standardized height classes ($\mu = 0$; s.d. = 1; n = 3 for the control and treatment combined) for Engelmann spruce in the ESSF Wet Alder Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

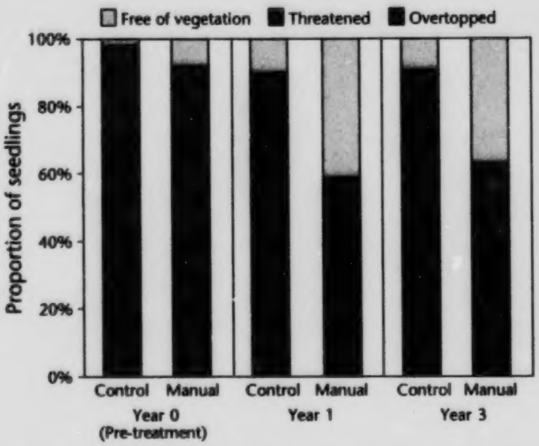


FIGURE 97 *Comparison of Engelmann spruce competitive status between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF* Wet Alder Complex. *Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

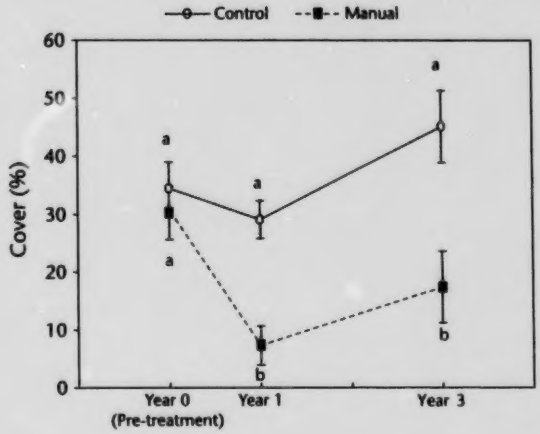


FIGURE 98 *Comparison of mean alder cover between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF* Wet Alder *Complex. Error bars represent one standard error of the mean* $(\bar{y})$ *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* (∝ = 0.10).

Means became significantly different as a result of a decrease in the variability among sites, possibly because of differences in the dates of pre-treatment and post-treatment assessments. In year 3, the same number of species (41) were recorded in the treatment and control. Species diversity was similar between the treatment and control in all assessments (p>0.10). Richness and diversity of structural vegetation groups were unaffected by manual cutting of the *Wet Alder* Complex (Table 93).

Except for the expected decrease in Sitka alder in treated plots, the abundance of other shrub species did not change on most sites (Table 94). Black huckleberry (*Vaccinium membranaceum*) was the most prominent wildlife food species on these sites, and its presence was unaffected by the cutting treatment. Among herbs, Sitka valerian (*Valeriana sitchensis*) decreased in cover in the treatment relative to the control on two of three sites, contrary to the expectation that individuals of that species would increase in size and vigour following canopy removal (Haeussler et al. 1990). White hawkweed (*Hieracium albiflorum*) also tended to decrease in abundance following manual cutting. Bunchberry (*Cornus canadensis*) was the only herb to increase in abundance following manual cutting of the *Wet Alder* Complex; it increased in cover in the treated plots of all three sites, and has also been observed to increase in abundance near stand edges (P. Burton, pers. comm., 2000). A number of other species of small stature increased in cover in the treated plots on single sites, perhaps partly because of increased light availability and partly because of increased visibility following manual cutting.

Competition Thresholds

Competition thresholds for Engelmann spruce stem diameter were estimated (a) from Sitka alder cover and (b) the competition index, CRH = (Sitka alder cover * Sitka alder modal height)/Engelmann spruce height. The cover and CRH thresholds for spruce diameter growth averaged 37 and 107%, respectively, and varied widely among the three sites (Table 95). The thresholds were not sharp at any of the sites, but above them there was a consistent decline in spruce diameter (e.g., Figure 101). On average, 23–30% of the trees were growing in

TABLE 90 *Cover and height of vegetation in the ESSF Wet Alder Complex before and after manual cutting in Engelmann spruce plantations*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Alder				
Cover (%)				
Pre-treatment	30.2	34.4	4.558	0.58
1 yr post-treatment	7.3	29.0	3.296	0.04*
3 yr post-treatment	17.4	45.1	6.189	0.05*
Height (cm)				
Pre-treatment	262.5	252.9	7.823	0.47
1 yr post-treatment	81.3	245.5	38.501	0.09*
3 yr post-treatment	146.3	266.5	17.063	0.01*
Fireweed				
Cover (%)				
Pre-treatment	21.3	17.7	2.271	0.38
1 yr post-treatment	14.6	11.6	3.152	0.58
3 yr post-treatment	20.2	12.7	3.628	0.20
Height (cm)				
Pre-treatment	118.9	117.3	6.933	0.88
1 yr post-treatment	85.7	90.6	1.651	0.17
3 yr post-treatment	99.9	91.7	4.886	0.53
All vegetation				
Cover (%)				
Pre-treatment	89.1	84.1	4.044	0.47
1 yr post-treatment	72.3	77.6	0.233	0.00*
3 yr post-treatment	78.5	80.4	4.067	0.89
All vegetation *(continued)*				
Height (cm)				
Pre-treatment	188.1	214.6	17.776	0.40
1 yr post-treatment	83.6	222.6	17.624	0.03*
3 yr post-treatment	134.4	244.7	16.475	0.01*
Shrubs				
Cover (%)				
Pre-treatment	55.7	53.4	5.393	0.80
1 yr post-treatment	40.2	57.8	2.45	0.04*
3 yr post-treatment	45.6	62.3	4.524	0.07*
Height (cm)				
Pre-treatment	238.9	228.8	16.161	0.70
1 yr post-treatment	101.0	237.5	29.270	0.08*
3 yr post-treatment	134.3	252.2	20.816	0.02*
Herbs				
Cover (%)				
Pre-treatment	44.7	43.1	1.597	0.54
1 yr post-treatment	40.3	32.2	5.675	0.42
3 yr post-treatment	42.7	36.9	4.961	0.23
Height (cm)				
Pre-treatment	92.8	82.0	9.083	0.49
1 yr post-treatment	65.0	72.3	2.989	0.22
3 yr post-treatment	80.6	65.4	7.039	0.31

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

neighbourhoods above the thresholds, and would benefit from further selective brushing. Most (85–90%) trees above the thresholds were control trees, whereas most (60%) below the threshold were treated trees. Most (90–95%) treated trees fell below the thresholds, indicating that brushing in this complex reduced alder cover and supposedly improved the trees' competitive environment. However, both the means (p>0.10) (Table 89) and the distributions of spruce diameters across alder neighbourhoods (e.g., Figure 101) were similar between the brushing treatment and control, indicating that spruce diameter had not responded to alder reductions. In addition, only 1% of treated spruce trees growing in alder neighbourhoods below the thresholds achieved ≥80% of the maximum diameter measured on the sites.

Linear regressions of spruce diameter versus Sitka alder cover were not significant for any of the three PROBE sites (p>0.10) (Table 95). This is because of the wide variability in spruce diameter across the broad range in localized alder covers. In contrast, linear regressions between spruce diameter and CRH were significant on all three sites (p<0.10), but adjusted r^2 values were low (0.12–0.21%) (Table 95). Fitting a negative exponential function to the diameter-CRH relationship marginally improved the adjusted r^2 value, from 0.12 to 0.14. The negative slopes indicate that Sitka alder had a competitive effect on spruce, but the nonsignificant cover regressions and low r^2 values for the CRH regressions suggest that alder competition was of secondary importance to spruce diameter growth on these sites.

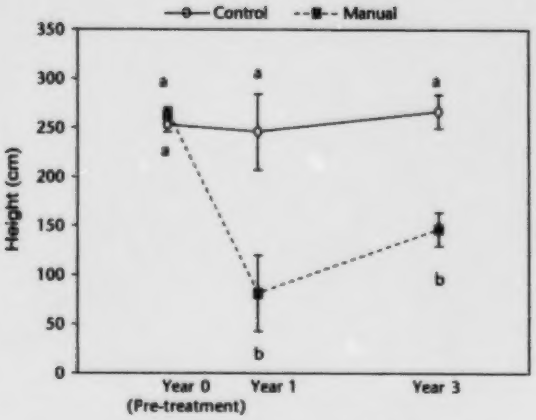


FIGURE 99 *Comparison of mean alder height between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the ESSF* Wet Alder *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (α = 0.10).*

TABLE 91 *Sprouting characteristics of Sitka alder in the ESSF* Wet Alder *Complex following manual cutting*

Response variable	Mean
Proportion of stumps with sprouts (%)	
1 yr post-treatment	72
3 yr post-treatment	58
Number of sprouts per stump	
1 yr post-treatment	4
3 yr post-treatment	4
Sprout length (cm)	
1 yr post-treatment	7
3 yr post-treatment	73

TABLE 92 *Richness and diversity of vascular plant species in the ESSF* Wet Alder *Complex before and after manual cutting in Engelmann spruce plantations*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Richness				
Pre-treatment	40.00	44.33	2.014	0.27
1 yr post-treatment	39.33	44.33	1.080	0.08*
3 yr post-treatment	41.33	41.33	2.858	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	2.35	2.30	0.077	0.71
1 yr post-treatment	2.58	2.42	0.042	0.11
3 yr post-treatment	2.39	2.28	0.167	0.69
Simpson's Diversity Index				
Pre-treatment	0.84	0.83	0.013	0.53
1 yr post-treatment	0.89	0.84	0.014	0.15
3 yr post-treatment	0.86	0.83	0.032	0.57

p-value denoted with "*" is significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 93 *Richness and diversity of structural vegetation groups in the ESSF* Wet Alder *Complex before and after manual cutting in Engelmann spruce plantations*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Richness				
Pre-treatment	6.33	6.67	0.236	0.42
1 yr post-treatment	6.67	6.67	0.408	1.00
3 yr post-treatment	7.00	6.67	0.236	0.42
Shannon-Weaver Diversity Index				
Pre-treatment	1.31	1.33	0.042	0.79
1 yr post-treatment	1.43	1.40	0.100	0.88
3 yr post-treatment	1.40	1.34	0.036	0.38
Simpson's Diversity Index				
Pre-treatment	0.67	0.68	0.015	0.61
1 yr post-treatment	0.71	0.71	0.038	0.99
3 yr post-treatment	1.40	1.34	0.015	0.85

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

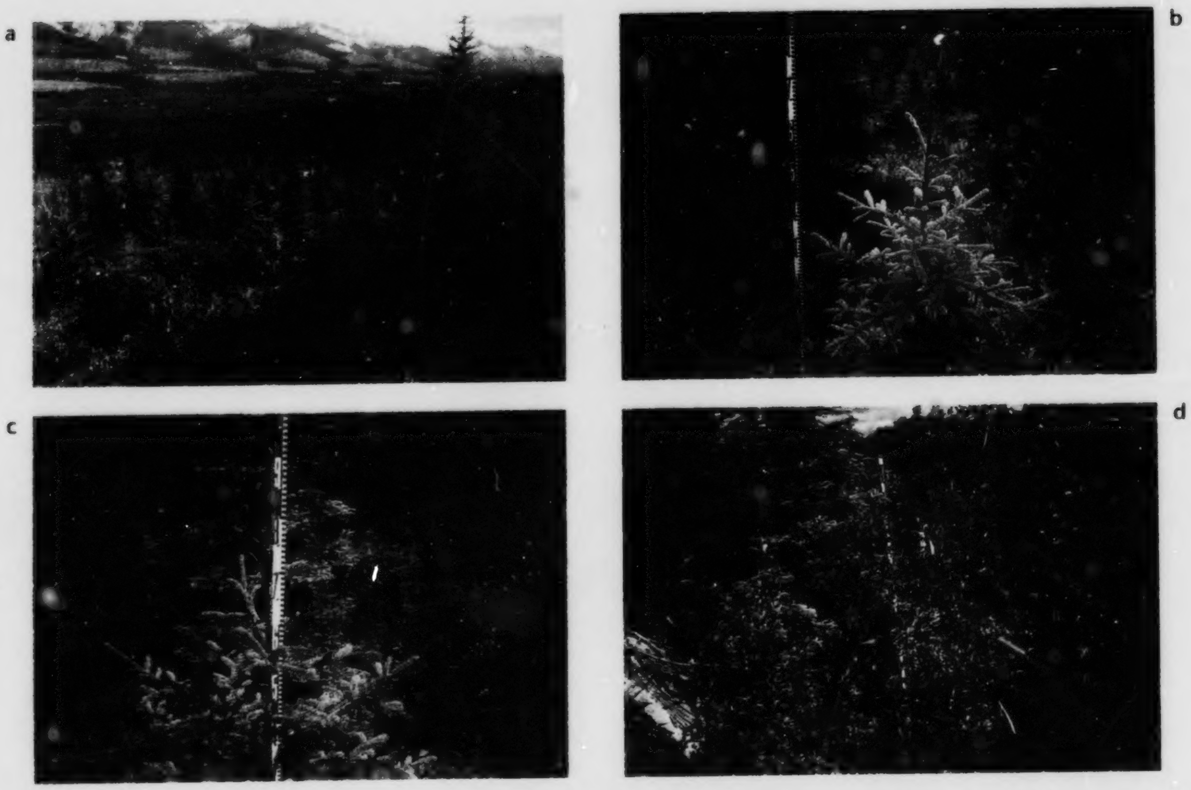


FIGURE 100 *Effects of manual cutting on the ESSF* Wet Alder *Complex and Engelmann spruce (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Alder recovered slowly following cutting.* Note: *Although the photo shows fifth-year responses, we report statistical results for only 3 years because not all replicate sites had been measured for 5 years. Photo credit: JMJ Holdings Inc.*

TABLE 94 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ESSF Wet Alder Complex in Engelmann spruce plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Tall shrubs		*Alnus viridis*	
Low shrubs			*Lonicera involucrata* *Lonicera utahensis* *Menziesia ferruginea* *Rhododendron albiflorum* *Ribes lacustre* *Rubus idaeus* *Spiraea betulifolia* *Vaccinium membranaceum*
Herbs	*Cornus canadensis*	*Hieracium albiflorum* *Valeriana sitchensis*	*Actaea rubra* *Arnica latifolia* *Carex* spp. *Clintonia uniflora* *Epilobium angustifolium* Grass spp. *Smilacina racemosa* *Smilacina stellata* *Streptopus amplexifolius* *Taraxacum officinale* *Thalictrum occidentalis*

TABLE 95 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Engelmann spruce stem diameter from the competition indices, alder cover and CRH, in the Wet Alder Complex in the ICH/ESSF zones*

Site	# of trees in the regression (n)	Conifer age (years)	Cover threshold (%)	Linear regression equation predicting diameter from alder cover[a]	Adjusted r^2 for linear regression predicting diameter from alder cover[a]	p-value for linear regression predicting diameter from alder cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
24	71	10	56	$y = 3.239 - 0.002\,x$	0.00	0.70	108	$y = 3.728 - 0.007\,x$	0.17	0.00	$y = 0.983\,e^{(-0.001 * x)}$	0.14
57	71	5	40	$y = 0.915 - 0.002\,x$	0.00	0.35	200	$y = 0.971 - 0.001\,x$	0.12	0.00		
104	60	8	15	$y = 4.387 - 0.022\,x$	0.01	0.20	13	$y = 4.852 - 0.027\,x$	0.21	0.00		
mean (s.e.)			37 (12)				107 (54)					

[a] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is alder cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (alder cover * alder modal height)/spruce total height.

[c] General form of non-linear equation is $y = a\,e^{(b\,x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

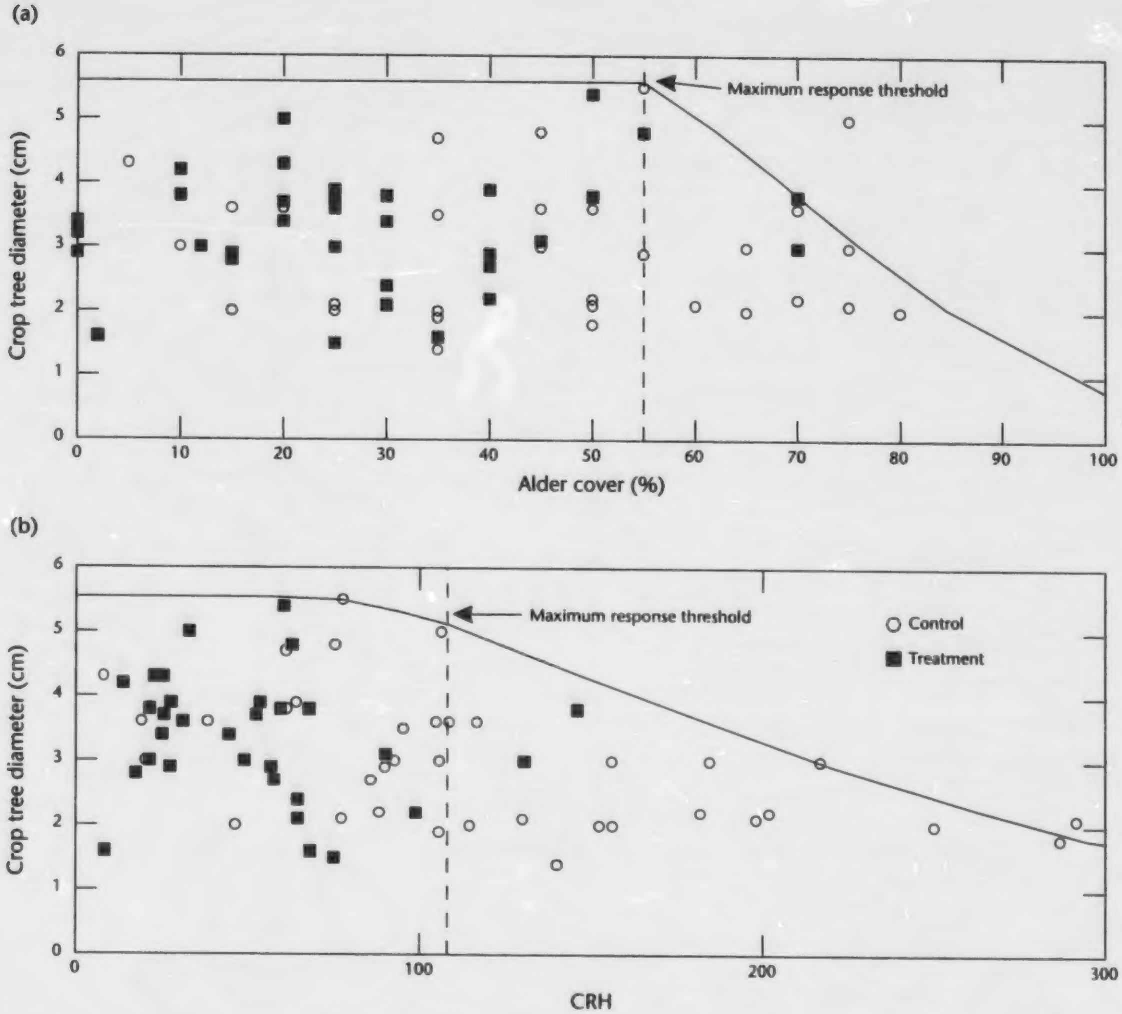


FIGURE 101 *Relationship between stem diameter of Engelmann spruce growing amongst the ESSF Wet Alder Complex and (a) alder cover or (b) CRH, where CRH = (alder cover * alder modal height)/spruce height. Data points include both treatment and control subplots for PROBE site 24 (n = 71). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989). Conifer diameter tended to be greater at intermediate than low cover and CRH values, possibly because of facilitation by the plant community. However, the boundary was drawn straight across to the y-axis to help identify the maximum response threshold.*

The *Wet Alder* Complex commonly occurs in dense thickets on rich, wet sites, and can affect conifer seedlings by intercepting light, reducing soil temperatures, and causing physical damage through snow- and vegetation-press. Manual and chemical brushing are often applied to increase survival and to ensure that free-growing standards are met. Here we discuss third-year responses of Engelmann spruce seedlings and the *Wet Alder* Complex in the southern interior ESSF zone to manual cutting applied in early to late summer.

Conifer Response

In spite of significant reductions in the abundance of a well-developed *Wet Alder* Complex, manual cutting did not significantly affect survival of Engelmann spruce seedlings in either the first or third years after manual cutting. However, spruce were 4–6 years old when brushing took place, and the variable stocking levels at that time suggest that there had already been considerable mortality on at least one site. We speculate that manual cutting could have improved survival if it had been applied when seedlings were younger. As of year 3, mortality was 12% higher in the treatment than in the control, but the difference was not significant because of high variability between sites. Most treatment mortality occurred on one site as a result of damage during cutting. Hart and Comeau (1992) comment on the danger of seedling damage during manual cutting, particularly where vegetation cover is heavy.

Manual cutting did not improve any measure of spruce growth in the first year after manual cutting, and treatment damage slightly reduced seedling vigour. In year 3, height:diameter ratio was 46.4 in the treatment versus 55.5 in the control (still well below stressful levels), suggesting that seedlings were becoming sturdier as a result of manual cutting, but there were no differences in stem diameter or height. Other studies have shown that seedlings commonly take longer than a single season to respond to treatment (e.g., Simard and Heineman 1996c; Simard, Heineman, and Youwe 1998; Whitehead and Harper 1998), and our seedlings may have been particularly slow to respond because they were 4–6 years old at the time of brushing, and likely experiencing considerable physiological stress. In another study, 17-year-old spruce seedlings on a high-elevation southern interior site were completely unable to respond to removal of an alder canopy (Stathers et al. 1994). According to Wagner et al. (1999), the critical period for reducing vegetation competition around black spruce seedlings was 1–3 years after planting. Delaying brushing for more than 1–2 years resulted in vegetation control having to be maintained for nearly twice as long as where treatments were applied promptly. In our study, an alternative explanation for the lack of seedling response is that a factor other than vegetation competition (e.g., short growing season, heavy snowpack, cold and wet soils) was limiting growth.

Plant Community Response

Manual cutting had a severe impact on the *Wet Alder* Complex that persisted for at least 3 years. In the first year after treatment, mean alder height was reduced from approximately 250 to 80 cm and cover from approximately 29 to 7%. In the following 2 years, alder cover increased to 45% in the control but only 17% in the treatment. Cut alder was gradually recovering in height, and 3 years after cutting, it was slightly more than half as tall as control alder. Abundance of the shrub layer and all vegetation was also significantly reduced by treatment for at least 3 years. Our study sites were treated on dates in June through August; however, cutting date is apparently of little consequence to treatment efficacy for Sitka alder (Hart and Comeau 1992; Lloyd and Heineman 1994b).

Alder in our study did not sprout vigorously and is not recovering rapidly following manual cutting, but the reasons for this are unclear. Sprouts averaged only 7 cm tall in the first-year assessment, and, although this can be partly attributed to a delay in brushing at one site (brushing took place at the beginning of the year one growing season rather than in the pre-treatment year), sprout growth was meagre on the other two sites as well. Between the first- and third-year assessments, sprout growth averaged 33 cm/yr, which is below anticipated rates; however, this is partly due to a second cutting at one site. Hart and Comeau (1992) suggest that a single manual cutting will not control the *Wet Alder* Complex because of the tendency for alder to sprout profusely and grow rapidly (up to 1 m/yr) under moist, high-nutrient site conditions. Although alder is recovering relatively slowly in our study, sprouts are increasing in height three times faster than slow-growing conifer seedlings and another cutting treatment may be necessary.

One and 3 years after the *Wet Alder* Complex was manually cut, there were no changes in abundance of the herb layer or fireweed. This is important because one of the risks associated with brushing this community lies in increasing the abundance of the herb and mixed-shrub layer growing under the alder canopy. Once the herb-shrub community is well developed, it may be harder to rehabilitate than the alder community. Stathers et al. (1994) found that glyphosate applied to the *Wet Alder* Complex reduced herb height in the first year, but herb cover increased relative to the control in the 2 subsequent years.

Three years after the *Wet Alder* Complex was manually cut, there were no differences in richness or diversity of either individual species or structural vegetation groups. A few herbs of low stature increased slightly in abundance following cutting. The species varied from site to site, however, except for bunchberry, which increased in cover across all three study sites.

Wildlife habitat values were moderately affected by manual cutting of the *Wet Alder* Complex. Cover for large and small wildlife species was reduced, and, on one site at least, this may have been beneficial to conifer seedlings because it reduced cover for rodents. Willow was common on another site, and although winter browse was likely reduced, sprouting increased summer browse for ungulates. At least one of the sites was in a cattle-grazing area, and slash from brushing appeared to reduce cattle traffic. Manual cutting of the *Wet Alder* Complex, which specifically targeted tall shrubs, had no effect on the abundance of low, berry-producing shrubs such as black huckleberry.

Effects of the Community on Resource Availability

The potential for seedlings to respond to brushing depends on whether limitations to growth are relieved. The limited response in our study may reflect ineffective release of resources following manual cutting or a delayed response to increased resource availability, or it may indicate that brushing did not address the primary cause of poor seedling performance.

The *Wet Alder* Complex often develops on sites where cold, wet, fine-textured soils hinder conifer seedling root development (Thorpe 1996). Balisky and Burton (1995) found vegetation cover to be a strong predictor of soil temperature, which suggests that brushing may have a slightly positive effect on soil thermal regime; however, brushing does not address the problem of excess soil moisture. Our southern interior sites (one mesic and two subhygric) ranged in elevation from 1350–1500 m, and were subject to many of the same limiting factors associated with sites in northern British Columbia (e.g., short growing season, heavy snowpack, and cold, wet soils). Numerous studies have documented the negative effects of low soil temperature and/or excess soil moisture on conifer seedling performance (e.g., Dobbs and McMinn 1977; Coutts 1981; Lopushinsky and Kaufmann 1984; Goldstein et al. 1985; Grossnickle 1987). Brand and Janas (1988) also demonstrated that the ability of white spruce to respond to brushing was dependent on soil temperature; if soil remained cold following treatment, there was little net benefit to seedlings. These authors suggested that brushing under such conditions could even worsen seedling condition by increasing transpiration demands in the absence of adequate root development. On our sites, reductions in alder cover were unlikely to improve cold, wet soil conditions.

Temporary reductions in alder abundance (i.e., following manual cutting) have little effect on nitrogen availability, nitrogen capital, or long-term site productivity (Simard 1990b; Sachs and Comeau 1992), whereas complete, sustained removal appears to have a negative effect. Simard (unpublished data) found that complete removal of alder for 10 years reduced nitrogen availability, and Brockley (pers. comm., 1999) measured less growth among pine growing in plots where alder was completely eliminated than where 10% cover was retained. Since alder re-sprouted in our study, it is unlikely that manual cutting decreased nitrogen fixation and availability.

Competition Thresholds

The competition thresholds for stem diameter of 4- to 6-year-old spruce averaged 37% for Sitka alder cover and 107 for CRH. Above the thresholds, interspecific competition appeared to be the most important factor limiting tree growth, setting the upper limit for spruce stem diameter. A small proportion (23–30%) of trees were growing in environments above the threshold, suggesting that competition was not constraining most trees in the population. Most of the trees above the threshold were control trees growing inside dense alder clumps. Below the thresholds, stem diameter was highly variable among both treated and control spruce trees: both minimum and maximum stem diameters occurred between 0 and 37% cover, and 0 and 107 CRH. Maximum stem diameters below the threshold may represent the growth potential of the site at low levels of competition, and the group of trees performing below the maximum may be constrained more by genetics, environment, and other factors, than by competition. It is important to note that many spruce were performing poorly even at low competition.

Lowering alder cover below the thresholds theoretically reduced the competitive constraint and provided the opportunity for greater spruce growth. Manual cutting was successful at reducing the abundance of alder below the thresholds for more than 90% of treated trees. However, the diameter distribution of treated spruce trees did not differ from that of control trees, nor was mean diameter affected by treatment as determined by ANOVA, indicating that brushing was ineffective at improving short-term growing conditions for target spruce. Only 1% of spruce that were brushed down to competition levels below the thresholds achieved at least 80% of the maximum growth potential measured on the sites. The lack of growth response may be related to trees being too suppressed to respond to treatment, the response being delayed, or factors other than interspecific competition limiting growth (e.g., initial seedling size, genetic variation, localized pockets of waterlogged and/or cold soil during critical root-growth periods, seedling vigour at the time of planting). These results illustrate the need to experimentally test hypothetical competition thresholds based on individual tree measurements.

The thresholds identified at the three replicate sites were characterized by consistent declines in spruce diameter, but were diffuse in nature. Other studies have similarly illustrated that thresholds for growth are fairly arbitrary points on continuous-response functions (Wagner et al. 1989). This phenomenon is a reflection of the genetic variability among trees, the heterogenous conditions in which they grow, and the variation in ability to respond to changing conditions. There was also considerable variability in thresholds among sites, particularly for CRH. This may be associated with variability in time since disturbance (7–22 years), and relative time of planting (spruce age range was narrow: 4–6 years). Although cover and height of alder did not vary widely among the sites, root systems may have developed more extensively with time since disturbance, resulting in more intense competitive interactions with newly planted seedlings on older sites. Notably, CRH and cover thresholds decreased with time since disturbance, indicating that lower levels (cover and height) of alder negatively affected spruce growth more on older than on younger sites.

The 37% alder cover threshold for 4- to 6-year-old spruce on our mesic wet alder sites was higher than that estimated by Simard (1990b) for 6- to 10-year-old lodgepole pine on mesic dry alder sites. Simard (1990b) tentatively identified competition thresholds of 10–40% alder cover for lodgepole pine diameter, and this was supported with subsequent experimental studies by Simard and Heineman (1996c) and Simard, Heineman, and Youwe (1998). There are two possible explanations for this difference. First, Engelmann spruce is more shade tolerant than lodgepole pine, and may therefore be more "competition tolerant," maintaining growth potential at higher levels of alder. Second, the *Wet Alder* Complex occurs on rich, wet sites, whereas the *Dry Alder* Complex develops on sites that are more nutrient-poor and that experience summer droughts. Conifers may tolerate higher alder abundance on wet alder than on dry alder sites because soils are wetter and richer, and therefore competition for soil resources is less intense. Our results, as well as those of Simard and others, indicate that competition thresholds are not highly portable across sites, among different target tree species, or during the course of stand development.

Effectiveness of Treatment at Meeting Management Objectives

Brushing treatments are applied to the *Wet Alder* Complex to improve conifer seedling survival and growth, and also to help meet the free-growing standards set out by the Forest Practices Code

(B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). On our study sites, the Code specifies target stocking of 1200 (minimum 700) well-spaced conifer stems/ha, and that, within 12–20 years of plantation establishment (9–15 years in the ICH zone) and at least 2 years after brushing, spruce must be 0.8 m tall (1.0 m in the ICH zone) and 100% as tall as neighbouring vegetation. Our third-year results show no significant improvements in survival or growth rates following manual cutting of the *Wet Alder* Complex, but the average height of seedlings in both the treatment and control was above the minimum height requirement. However, alder in the cutting treatment is again (on average) taller than seedlings, and another brushing treatment is expected to be required for seedlings to meet the conifer:vegetation height ratio requirement (B.C. Ministry of Forests 2000) (Figure 102). Recent studies involving the *Dry Alder* and *Willow* complexes showed that brushing intervention was not required for lodgepole pine and Engelmann spruce seedlings to outgrow vegetation by age 10 to 11 (Simard and Heineman 1996b, 1996c; Simard, Heineman, and Youwe 1998). However, height of those shrub canopies was consistently less than 2 m, whereas it can be more than 5 m in the *Wet Alder* Complex, and lodgepole pine height growth exceeded that of our spruce.

It can be difficult to establish seedlings on sites occupied by the *Wet Alder* Complex. Thorpe (1996) suggests that, considering the riparian values often associated with these sites, performance expectations for this complex should be re-examined. Brushing treatments are costly, particularly if they are repeated and have a low likelihood of success because they do not address major site limitations. The best way to control a well-established *Wet Alder* Complex may be the application of site preparation treatments that damage or destroy alder root systems (Boateng and Comeau 1997c), but subsequent brushing treatments will probably also be necessary. As backlog NSR declines in the southern interior, however, there should be less need to treat the fully developed *Wet Alder* Complex.

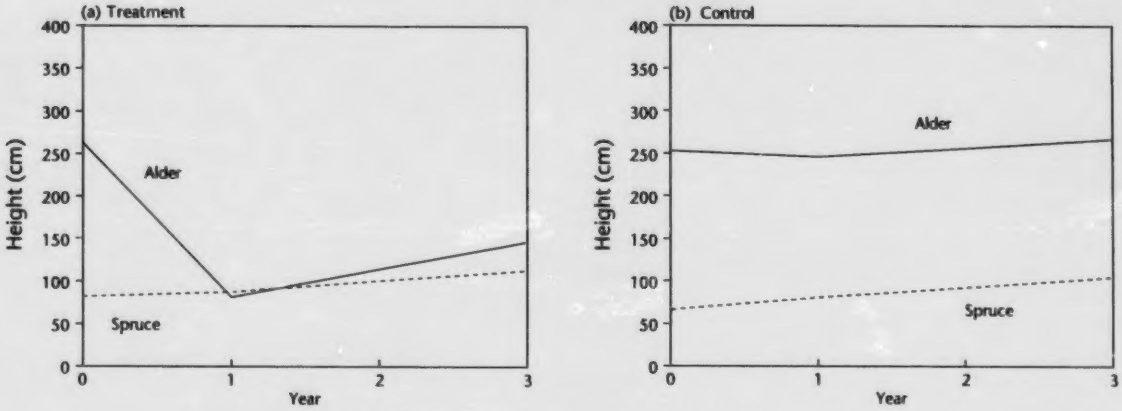


FIGURE 102 *Comparison of average Engelmann spruce and alder height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ESSF* Wet Alder Complex. *Values for year 2 were interpolated from actual data. Spruce are not predicted to outgrow alder within the free-growing assessment window.*

Manual cutting of the *Wet Alder* Complex did not improve Engelmann spruce survival or growth in the first year after treatment. By year 3, height:diameter ratio was lower in the treatment than in the control, but even in the control, it was not high enough to suggest seedling stress. Manual cutting significantly reduced the abundance of alder, and its recovery rate was relatively slow. Still, 3 years after cutting, alder was growing faster than spruce seedlings, and the proportion of overtopped trees was increasing. Another treatment will likely be necessary to meet the conifer:vegetation height ratio requirement for free-growing (B.C. Ministry of Forests 2000). Three years after manual cutting of alder, the herb layer had not increased significantly in abundance.

Reducing alder abundance below the competition threshold of 37% cover did not affect the mean or distribution of spruce stem diameters, suggesting that it was too early to expect a response, that spruce above the threshold were too suppressed to respond to release, that factors other than competition were more limiting to spruce growth, or that our measures of competition were too crude to adequately reflect the competitive environment.

It is possible that treatments in our study were applied too late (seedlings were 4–6 years old) to affect survival. There had been considerable mortality prior to brushing on at least one of the sites. Wet alder sites are difficult to treat, and site factors other than competing vegetation may be limiting seedling performance.

MANAGEMENT IMPLICATIONS

1. Our study suggests that manual brushing of the *Wet Alder* Complex on subhygric and mesic sites in the ESSF and ICH zones is unlikely to improve survival or growth of Engelmann spruce seedlings that are 4–6 years old at the time of treatment. Seedlings may respond if they are brushed at a younger age, but further research is required on this topic.
2. Seedlings on one site sustained considerable damage during manual cutting, which reduced overall survival and vigour in comparison with the control. Manual cutting should be done with particular care on sites where seedlings are small, alder is dense, and there is a well-developed herb layer that reduces seedling visibility.
3. Manual cutting reduced height and cover of alder, shrubs, and overall vegetation. Alder stumps did not sprout vigorously and the community is not recovering quickly. This contradicts other studies where alder in this complex sprouted vigorously following cutting, however, and further study is needed to identify factors that affect rates of sprouting and sprout growth.
4. Other studies suggest that the *Wet Alder* Complex is best managed with prompt mechanical site preparation and planting following harvest. Backlog NSR is declining in the southern interior, so there is less occasion to prescribe brushing treatments for the fully developed community.
5. We estimate that competition thresholds for spruce diameter growth are 37% alder cover and 107 CRH.
6. There is no evidence that plant diversity in the *Wet Alder* Complex was negatively affected by manual cutting. In fact, diversity increased in the treatment relative to the control because alder dominance was reduced. The availability of wildlife food is unlikely to be reduced by manual cutting of the *Wet Alder* Complex, since black huckleberry, the only species of known importance, was unaffected by treatment.

SECTION 10

Aspen Complex

ABSTRACT

We have third-year results demonstrating the effects of manual cutting on lodgepole pine that were 7–10 years old at the time of treatment and the *Aspen* Complex in the IDF and MS zones. Manual brushing improved stem diameter increment and height:diameter ratio of lodgepole pine growing among 26% cover of aspen within 3 years, but there were no improvements in stem diameter, height, or leader length. Pine survival was 100% in both the treatment and control during the 3-year measurement period, and most trees were healthy regardless of whether brushing was done. Manual cutting resulted in large between-site variability in broadleaf height and cover in the first year after treatment, resulting in no significant differences between the treatment and control. In year 3, broadleaf height was significantly less in the treatment (166.3 cm) than in the control (367.4 cm), but cover continued to be unaffected.

Competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for total aspen density, 31 and 21% for total aspen cover, and 31 and 19 for CRH (aspen cover * aspen modal height)/conifer height, respectively. Aspen of all heights relative to target conifers were used in estimation of the thresholds. These thresholds, as well as other competition studies in young aspen-conifer mixtures, suggest that lodgepole pine and Douglas-fir growth rates will not be adversely affected by moderate levels of aspen abundance.

Manual brushing eliminated tall broadleaves and created free-growing stands of lodgepole pine in our study. In contrast, our results suggest control pine would be unlikely to meet the conifer:vegetation height ratio or density requirements for free-growing under the new guidelines (B.C. Ministry of Forests 2000). Cutting aspen had no lasting effects on the richness or diversity of individual species or structural vegetation groups.

Description of the *Aspen* Complex

The *Aspen* Complex is characterized by relatively pure stands of trembling aspen (*Populus tremuloides*), but paper birch (*Betula papyrifera*) and cottonwood (*Populus trichocarpa*) may also be present in lesser quantities (Figure 103). On sites where birch and/or cottonwood are at least as abundant as aspen, the community is classified as the *Mixed Broadleaf-Shrub* Complex, described in Section 11. Common understorey species associated with the *Aspen* Complex are fireweed (*Epilobium angustifolium*), thimbleberry (*Rubus parviflorus*), and pinegrass (*Calamagrostis rubescens*).

The *Aspen* Complex occurs throughout the IDF, MS, and ICH zones in the southern interior of British Columbia (Kimmins and Comeau 1990) and is also common in most zones in the northern interior (Butt 1988). Trembling aspen is a seral species in at least 77 subzones or variants of nine biogeoclimatic zones in British Columbia (Peterson and Peterson 1995), and is the most widespread tree species in North America (Burns and Honkala 1990).

Development of the *Aspen* Complex

Aspen occurs across a range of moisture and nutrient regimes, but is most productive on fresh to moist, well-drained sites with high levels of nutrients (Krajina et al. 1982; Angove and Bancroft 1983; Klinka and Scagel 1984; Haeussler et al. 1990). In the southern interior dry belt (PP and IDF zones), mature aspen stands often occupy moist, rich sites (i.e., gullies, floodplains) and also talus slopes; they are abundant in some areas of the MS zone and not in others; and in the wet belt (ICH zone), they are often found on rich, fluvial toe slopes (D. Lloyd, pers. comm., 2000). However, dense stands of juvenile aspen commonly develop following logging on mesic and submesic sites in all three zones (Mather 1988). It does not usually occupy nitrogen-poor sites because it has high nitrogen requirements (Peterson and Peterson 1995). Aspen helps improve nutrient availability through its rapid rate of litter decomposition, rapid growth rate, and high nitrogen uptake (Paré and Van Cleve 1993). Aspen is very shade-intolerant (Krajina et al. 1982).

FIGURE 103 *The* Aspen Complex *prior to manual cutting at McConnell Lake (Site 66) in the IDFdk1 variant in the Kamloops Forest District. Photo credit: Jean Mather.*

Aspen reproduces primarily by suckering from parent tree roots; reproduction from seed is uncommon because seed is short-lived and requires constant moisture, and also because seedling survival and growth are reduced at temperatures exceeding 30°C (Doucet 1989). Occasionally, seedlings can establish in abundance in localized patches, but little is known about the factors governing their success (D. MacIsaac, pers. comm., 2000). Sucker initiation and growth are promoted by high light levels and warm soils (to an optimum of 23°C) (Burns and Honkala 1990), so treatments that remove the canopy (e.g., clearcut harvesting) and expose mineral soil (e.g., scarification and severe broadcast burns) tend to promote suckering. Treatments that break up the root system (e.g., deep ploughing to 30 cm) (Haeussler et al. 1990) or compact the soil (Kabzems 1996) are reported to reduce suckering. In dry ecosystems, however, soil ripping has been observed to encourage sprouting (T. Newsome, pers. comm., 2000).

Aspen suckers appear soon after disturbance (Bailey and Anderson 1979; Zieroth 1984; Debyle and Winokur 1985; Burns and Honkala 1990), and early growth tends to be rapid. Under ideal conditions, suckers can grow 2 m the first year (Steneker 1976). Vigorous growth such as this occurs in the southern ICH zone (Simard and Vyse 1992), but elsewhere in the southern interior, 1-year-old suckers are commonly less than 1 m tall (Haeussler et al. 1990). Aspen is capable of growing to a height of 9 m within 8 years (Perala 1987); however, on our PROBE sites in the IDF and MS zones, height was about 3 m after 8 years. Aspen grows more slowly in the northern than the southern interior of British Columbia, but can still reach 5–9 m by age 15 years (Bella 1986; Butt 1988; Doucet and Veilleux 1982, cited by Doucet 1989). Initial sucker densities of 30 000–100 000 stems/ha are common (Jones 1976; Crouch 1983; Bella 1986; Doucet 1989, citing Doucet 1979), but self-thinning is rapid because of aspen's shade-intolerance. On PROBE sites in the southern interior, aspen density averaged 28 000 stems/ha (16% cover) 8 years after mechanical site preparation. Similar aspen densities were observed on cutovers in northern British Columbia by Butt (1988).

Interactions with Conifer Seedlings

Aspen is considered a serious competitor to conifers throughout most of interior British Columbia, including the southern interior (Kimmins and Comeau 1990). The exception may be the wetter ICH subzones of the southern interior, where birch tends to be the dominant broadleaf species, and aspen densities are rarely high enough to reduce survival and growth of young conifers (Mather 1988). In north-central British Columbia, high densities of aspen can reduce light and soil moisture to levels that are limiting to conifer growth for at least part of the growing season (DeLong and Tanner 1996); however, the severity and nature of aspen competition appears to vary from southern to northern British Columbia and from wet to dry ecosystems.

Aspen may also indirectly reduce health of young conifers because it is the primary host of the rust fungus *Melampsora albertensis.* Alternate hosts are conifers, including Douglas-fir and lodgepole pine (Callan 1996). Douglas-fir, in particular, may be reduced in vigour if they are growing among infected aspen clones (J. Wright, pers. comm., 2000).

In spite of its ability to compete for resources, aspen also benefits conifers in several ways. It takes up large amounts of nutrients, especially calcium, at an early age and retains them within the ecosystem (Pastor 1990). It may also slow the spread of root disease in mixed stands because it is immune to *Phellinus weirii* (Morrison et al. 1991) and more resistant to *Armillaria ostoyae* than most conifers (Peterson and Peterson 1995). Mature aspen canopies also reduce frost damage to seedlings in the understorey (DeLong et al. 2000) by restricting radiative heat loss during the night and improving air temperatures at seedling height (Stathers 1989). Because of its sucker-origin communal root system, aspen is mechanically stable (Strong and La Roi 1983), and its presence may increase resistance of neighbouring conifers to windthrow (Frivold 1985; Yang 1989).

Importance to Wildlife and Range

Aspen ecosystems are extremely important to wildlife, providing habitat for at least 55 species of mammals and 135 species of birds (DeByle and Winokur 1985; Peterson and Peterson 1995). Dense stands of sapling aspen, pure maturing aspen forests, and mixed aspen-conifer forests all provide different habitats for wildlife, but species diversity is probably greatest in mixed stands because of the variety of niches they provide (DeByle and Winokur 1985).

Aspen leaves, particularly those on suckers, are highly nutritious and provide summer food for moose, elk, and deer (DeByle and Winokur 1985). In winter, these animals sometimes browse on the bark of mature trees (Banfield 1974). In addition, ungulates favour many of the understorey plants associated with aspen stands (DeByle and Winokur 1985). Aspen communities also provide ungulates with cover (Peterson and Peterson 1995). Invertebrates and small mammals, including mice, voles, shrews, and chipmunks, commonly utilize dead or downed trees in aspen forests (Peterson and Peterson 1995). Porcupines feed on aspen leaves and twigs in spring and summer and bark in winter, and beaver utilize it for food and dam-building materials (Banfield 1974; Enns et al. 1993; Peterson and Peterson 1995). Mixed aspen-conifer stands provide both habitat and food for snowshoe hares (DeByle and Winokur 1985). Aspen forests have about twice the density and diversity of insects as pure conifer stands, and consequently attract insectivores such as bats (Peterson and Peterson 1995). Black bears feed on small mammals that live in early seral to mature aspen stands, and they also forage on aspen buds in the spring (Debyle and Winokur 1985; Enns et al. 1993).

The *Aspen* Complex is also commonly utilized for livestock range. Aspen suckers are highly nutritious, and can contribute substantially to livestock diets, although cattle are deterred from entering young aspen stands when they are very dense (DeByle and Winokur 1985). Young aspen sprouts are a preferred forage for sheep (Newsome et al. 1995). Livestock also commonly graze on pinegrass and other understorey plants associated with the *Aspen* Complex (McLean 1979; Quinton 1984).

Common Brushing Treatments in the *Aspen* Complex

The *Aspen* Complex is operationally brushed using a variety of methods in southern interior British Columbia, including manual cutting, girdling, foliar glyphosate application, basal triclopyr application, and cut-spray glyphosate (manual cutting followed by foliar glyphosate application to new sprouts) (Table 96). Broadcast treatments are the most common, but some recent silviculture prescriptions have called for retention of up to 1000 aspen stems/ha.

Historically, the most common brushing treatments applied to this community have been manual cutting in relatively young aspen stands and girdling in stands dominated by larger-diameter (>5 cm) trees. Girdling is often preferred over manual cutting because it results in less re-growth (DeByle and Winokur 1985). Girdling inhibits suckering because severing the phloem results in a lower ratio of cytokinins to auxins (C:A) in roots (cytokinins stimulate sucker initiation and auxins depress it), whereas cutting encourages suckering because severing both the phloem and xylem increases root C:A. In stands with a range of aspen diameters, a combination of girdling and cutting is commonly employed. Girdling is as effective as herbicides for killing aspen, probably costs about the same amount, and does not have the complication of requiring permits (Peterson and Peterson 1995). Herbicide treatments that control aspen include foliar spray or stem injection of glyphosate, foliar or basal application of triclopyr, soil application of hexazinone, and cut stump–2,4-D amine (Biring et al. 1996).

TABLE 96 *Common brushing treatments applied to the Aspen Complex in the southern interior of British Columbia*

Treatment	Objective	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantage
Manual cutting	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Power saw 2. Motorized brush saw	$538 $538	1. Root suckering
Girdling	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Chain girdler	Unknown	1. Extended reductions in aspen may negatively affect wildlife 2. Suitable only for aspen stands >5 cm diameter
Cut, then spray sprouts with glyphosate	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Saw and backpack sprayer or squirt bottle	Unknown	1. More expensive than manual cutting (requires two entries) 2. Extended reductions in aspen may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Foliar glyphosate spray	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Backpack sprayer	$700	1. Suitable only for young (short) aspen stands 2. Extended reductions in aspen may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Basal triclopyr application	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Sprayer 2. Roller	Unknown	1. Extended reductions in aspen may negatively affect wildlife 2. Difficulties obtaining herbicide permits

[a] Based on average costs for the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)

Manual Cutting

This section describes third-year lodgepole pine and vegetation responses to manual cutting of the *Aspen* Complex in the IDF and MS zones (n = 3). Pine were 7–10 years old at the time of treatment.

Lodgepole pine in the IDF and MS zones

Description of study sites and treatments
The three study sites for this treatment cell are widely distributed through the Kamloops Forest Region. The McConnell Lake site is in the Thompson Dry Cool IDF variant (IDFdk1), 18 km south of Kamloops in the Kamloops Forest District; the Kathleen Lake site is in the Cascade Dry Cool IDF variant (IDFdk2), northwest of Summerland in the Penticton District; and the Fowler Creek site is in the Thompson Dry Mild MS variant (MSdm2), 10 km east of Falkland in the Salmon Arm District. All the sites are mesic, situated in mid-slope positions, with Brunisolic silt loam soils (Table 97). The IDF sites have moderately sloping (30–50%) southerly aspects, and the MS site has a 20% easterly aspect. Elevations range from 1220 to 1400 m.

The original stands were clearcut between 1982 and 1988, 8–10 years before brushing. The McConnell Lake and Fowler Creek sites were mechanically prepared 1–2 years after logging, then immediately planted with lodgepole pine. The Kathleen Lake site was left to regenerate naturally without preparation. At the time of brushing, the 7- to 10-year-old lodgepole pine averaged 1.6–2.0 m and was more than two-thirds the height of neighbouring vegetation. Pine were growing at an average rate of 38 cm/yr compared to 46 cm/yr for aspen. All three sites were well stocked with at least 1000 well-spaced conifers/ha. Total conifer density was 1539–2100 stems/ha on the sites that were mechanically prepared and 8136 stems/ha on the unprepared site. All aspen were cut near ground level in September at the McConnell Lake and Fowler Creek sites, whereas, at Kathleen Lake, aspen smaller than 5 cm dbh was cut near ground level and the larger trees were girdled 1 year later (Table 98).

Conifer response
Survival and vigour Three years after manual cutting, survival of 10- to 13-year-old lodgepole pine (7–10 years old at the time of treatment) was 100% in both the manual cutting treatment and control (p = 1.00) (Table 99), and most trees were healthy (good or moderate vigour) (Figure 104). There was a slight decrease in pine vigour 1 year after cutting, but seedlings outgrew this by year 3.

Growth Lodgepole pine did not respond within 1 year of manual cutting, but after 3 years, diameter increment was larger in the treatment than in the control (0.72 versus 0.51 cm, p = 0.02) and height:diameter ratio was smaller (55.6 in the treatment versus 66.3 in the control, p = 0.05) (Table 99, Figure 105). Stem diameter and height were unaffected by cutting (p>0.10) (Figure 106), and leaders showed a negative response in year 3 (40.6 in the control versus 37.6 cm in the treatment, p = 0.00). Three years after manual cutting, when pine were 10–13 years old, they averaged 310.6 cm tall and had 5.48-cm stem diameters.

Standardized distributions for pine stem diameter and height were normal both pre- and post-treatment, and were similar in the treatment and control throughout the measurement period (Figures 107 and 108). The distributions support ANOVA results that pine diameter and height growth did not improve as a result of brushing.

Competitive status Prior to manual cutting, 25% of pine were free of vegetation, 28% were threatened, and 47% were overtopped (Figure 109). Three years later, 87% of treated pine were free of vegetation, 6% were threatened, and only 7% were overtopped. The competitive status of pine in the control was also improving; in year 3, 63% were free of vegetation, 16% were threatened, and 21% were overtopped.

Plant community response
Abundance Although broadleaf abundance was reduced by manual cutting, differences in height and cover were not significant 1 year after cutting (p>0.10) (Table 100). The lack of statistical significance could be explained by the variability among sites. One of the sites was treated over a period of 2 years, where small aspen were initially cut and

TABLE 97 *Characteristics and history of the three replicate study sites where the IDF/MS Aspen Complex was manually cut in lodgepole pine stands*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
McConnell Lake PROBE 66 Kamloops District	IDFdk1 01 (mesic)	1300	S 30%	Brunisol/ silt loam	Clearcut 1988 MSP and spot burned 1989	8	7	0	P 1989	PSB 211 1+0	7	163 (36)	Aspen cover: 17 (11) Aspen height: 183 (57)	2100	1000
Kathleen Lake PROBE 27 Penticton District	IDFdk2 01 (mesic)	1400	S 50%	Brunisol/ silt loam	Clearcut 1982	10	n/a	n/a	N	n/a	10	169 (40)	Aspen cover: 45 (19) Aspen height: 381 (65)	8136	1000
Fowler Creek PROBE 58 Salmon Arm District	MSdm2 05 (mesic)	1220	E 20%	Brunisol/ silt loam	Clearcut 1985/86 MSP and spot burned 1988	9	7	0	P 1989	PSB 313 1+0	7	199 (47)	Aspen cover: 17 (17) Aspen height: 412 (172) Broadleaf cover: 23 (18) Broadleaf height: 363 (171)	1539	1089

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 98 *A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the IDF/MS Aspen Complex*

Site	Treatment date	Treatment type	Treatment specification
McConnell Lake	September 6, 1996	Broadcast	All broadleaves >15 cm tall were cut near ground level
Kathleen Lake	July 1992	Broadcast	Broadleaves <5 cm dbh were cut near ground level; larger stems were girdled 1 year after manual cutting
Fowler Creek	Late September 1995	Broadcast	Broadleaves and shrubs within 2 m of the drip line of pine seedlings were cut. Smaller vegetation was cut within 1 m of the drip line.

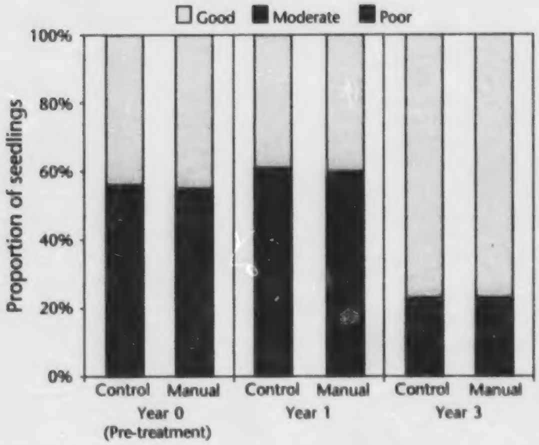


FIGURE 104 *Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen Complex. Good-vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor-vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

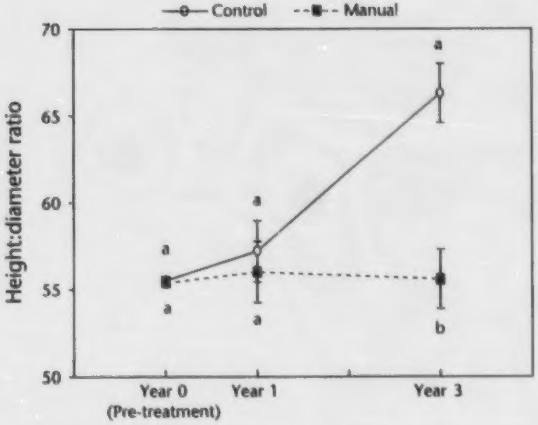


FIGURE 105 *Comparison of mean lodgepole pine height:diameter ratio between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen Complex. Error bars represent one standard error of the mean* $(\bar{y})$ *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* $(\propto = 0.10)$.

TABLE 99 *Survival and growth responses of lodgepole pine to manual cutting in the IDF/MS Aspen Complex*

	Means			
Response variable	**Manual cutting**	**Control**	**Standard error**	**p-value**
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	100	100	0.000	1.00
3 yr post-treatment	100	100	0.000	1.00
Stem diameter (cm)				
Pre-treatment	3.28	3.27	0.223	0.97
1 yr post-treatment	4.02	3.96	0.211	0.84
3 yr post-treatment	5.81	5.15	0.222	0.17
Diameter increment (cm)				
1 yr post-treatment	0.76	0.75	0.044	0.88
3 yr post-treatment	0.72	0.51	0.019	0.02*
Height (cm)				
Pre-treatment	175.6	178.4	10.374	0.87
1 yr post-treatment	213.3	220.1	13.447	0.76
3 yr post-treatment	298.6	322.6	17.515	0.43
Leader length (cm)				
Pre-treatment	37.6	38.9	2.702	0.76
1 yr post-treatment	36.9	43.1	6.066	0.54
3 yr post-treatment	37.6	40.6	0.069	0.00*
Height:diameter ratio				
Pre-treatment	55.4	55.5	0.234	0.77
1 yr post-treatment	56.0	57.2	1.763	0.68
3 yr post-treatment	55.6	66.3	1.699	0.05*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

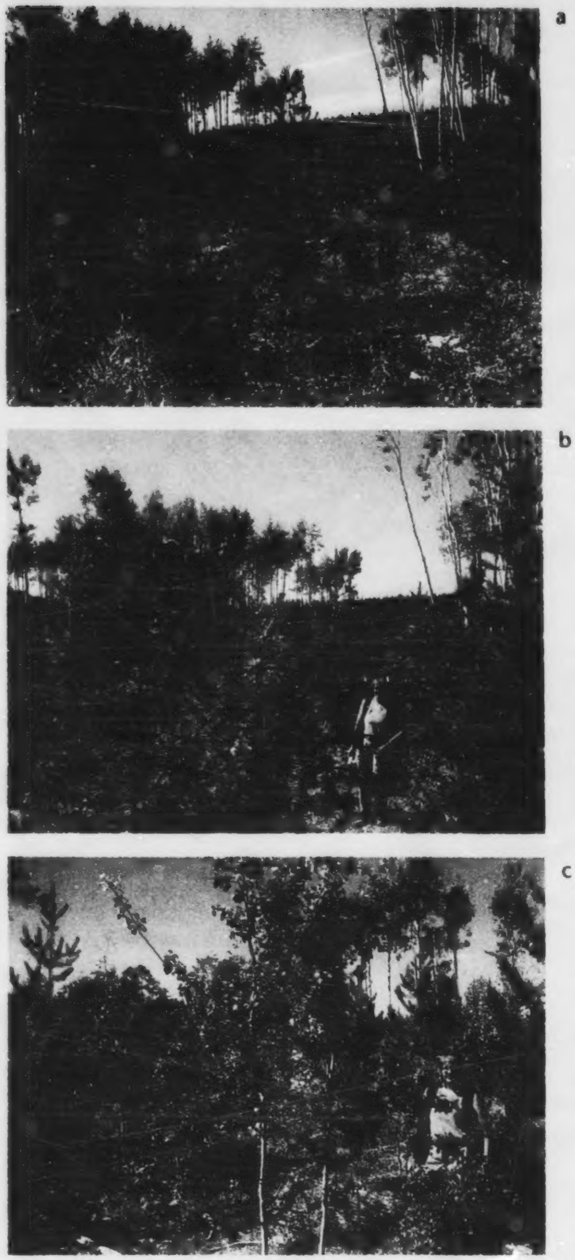


FIGURE 106 *Effects of manual cutting on the Aspen Complex and lodgepole pine (a) 1 year and (b) 3 years following treatment. The control (c) is shown 3 years post-treatment for comparison. Logepole pine height and diameter were unaffected by the treatment. Photo credits: Jean Mather and Ed Yourk.*

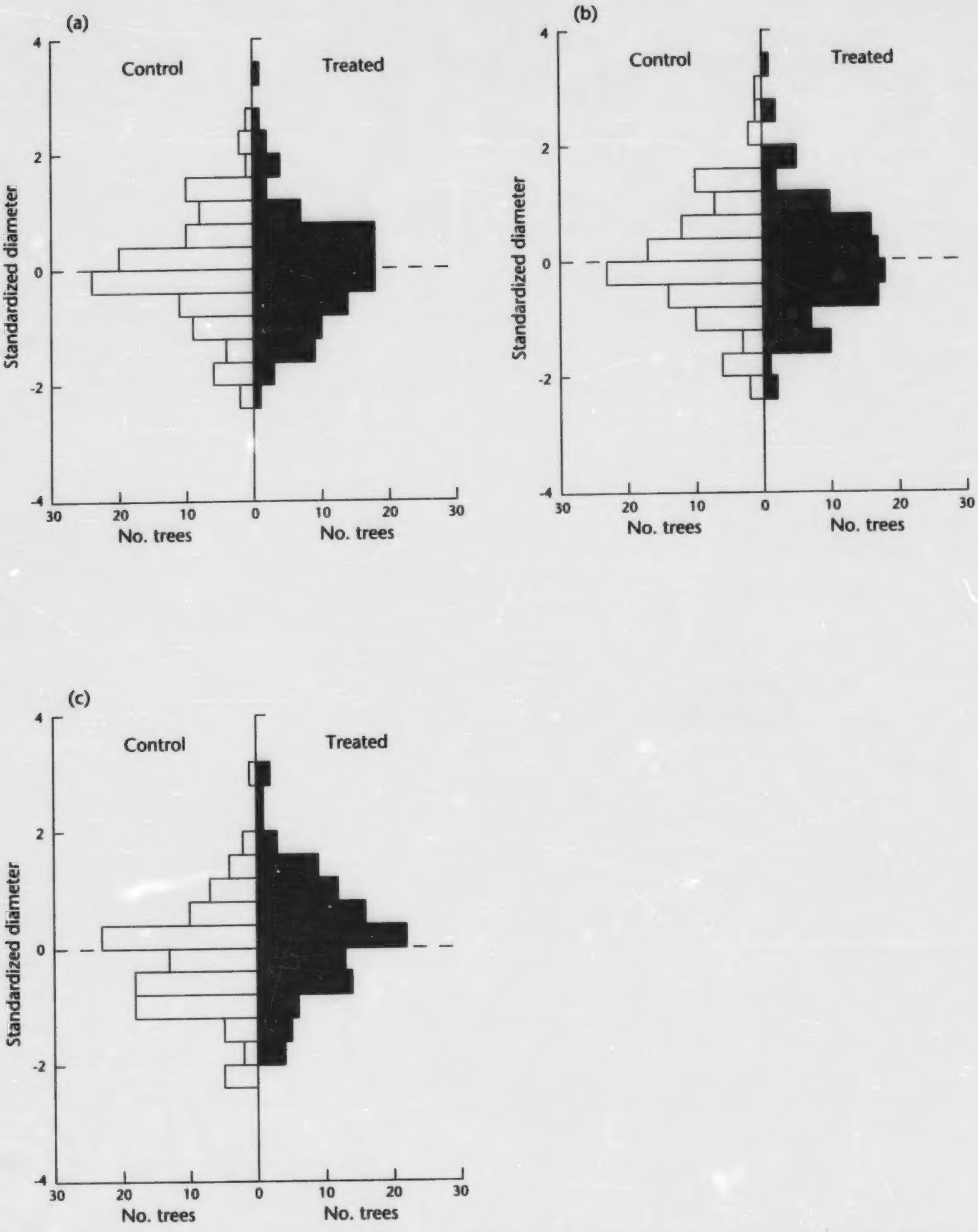


FIGURE 107 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the IDF/MS Aspen Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

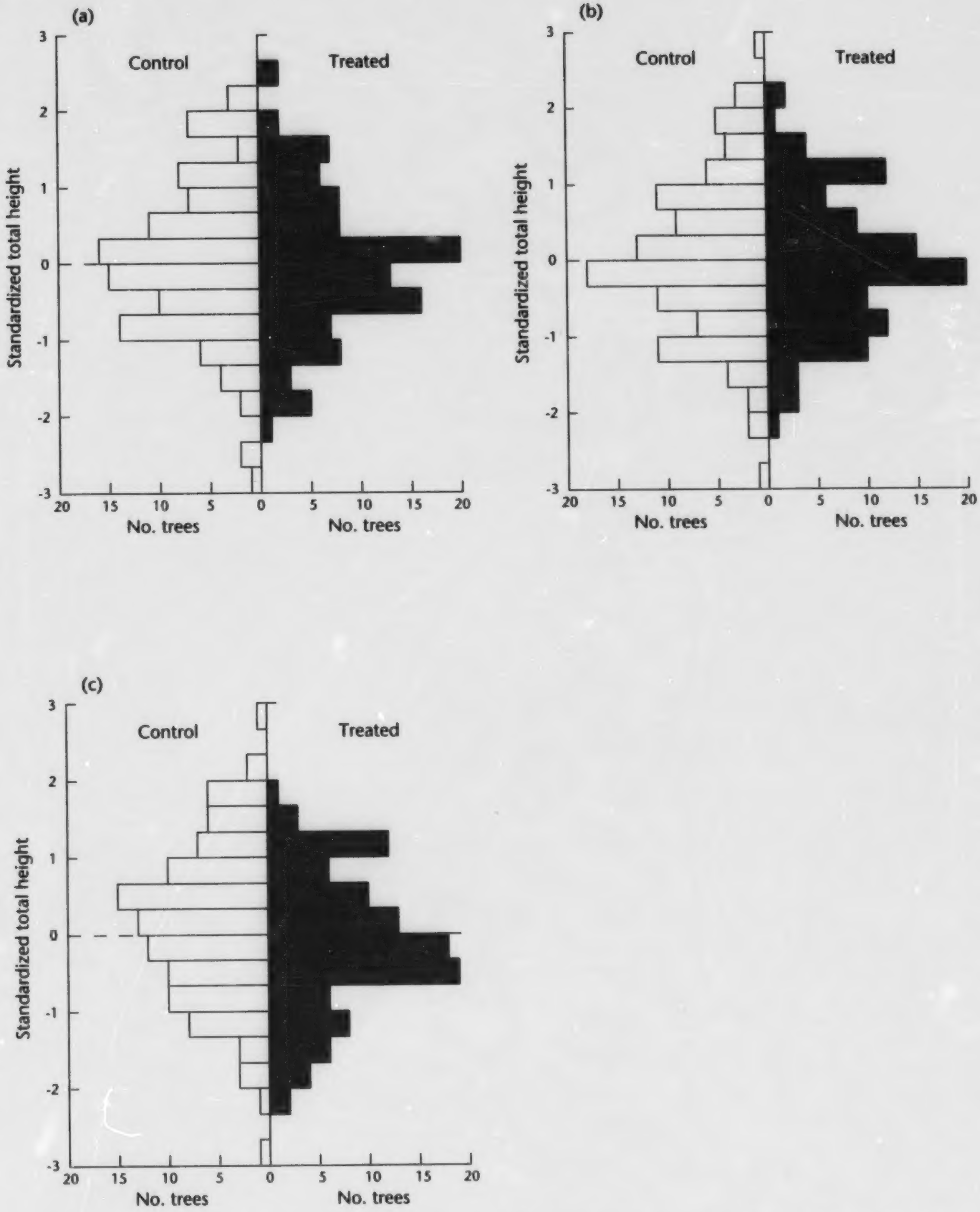


FIGURE 108 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the IDF/MS Aspen Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment.*

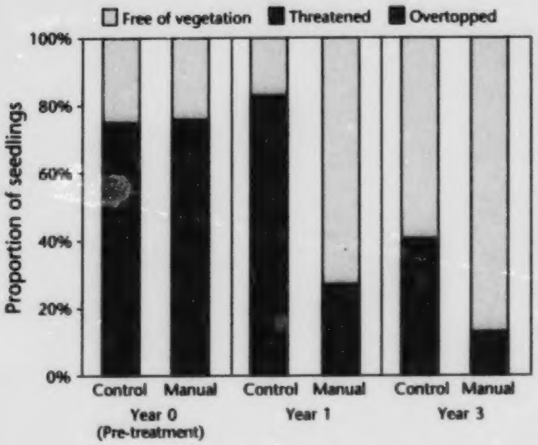


FIGURE 109 *Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS Aspen Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

larger stems were girdled the following year, whereas aspen at the other two sites were all treated at once. By year 3, broadleaves were significantly shorter in the treatment compared to the control (166.3 versus 367.4 cm, $p = 0.08$) (Figure 110), but their cover remained unchanged. Reductions in height and cover of aspen alone were not statistically significant because of the variability among sites ($p>0.10$). In year 3, aspen was shorter in the cutting treatment than in the control (194.4 cm versus 509.5 cm, $p = 0.11$). It was visually obvious that brushing reduced total density of aspen, but post-treatment density was not calculated because the measurements were missing from some plots on some sites. Cover and height of shrubs were unaffected by the manual cutting treatment. There was a short-lived decrease in herb cover in the treatment compared with the control in year 1 (66.9 versus 62.5%, $p = 0.03$), but this effect had disappeared by year 3.

Suckering Almost all (94%) of the cut aspen produced suckers in close proximity to stumps within 1 year of treatment (Table 101). There averaged

TABLE 100 *Cover and height of vegetation in the IDF/MS Aspen Complex before and after[a] manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Aspen				
Cover (%)				
Pre-treatment	26.6	25.5	0.635	0.34
1 yr post-treatment	13.5	21.5	4.683	0.35
3 yr post-treatment	23.2	25.5	7.924	0.85
Height (cm)				
Pre-treatment	305.9	346.4	37.291	0.52
1 yr post-treatment	213.1	372.3	105.327	0.40
3 yr post-treatment	194.4	509.5	81.249	0.11
Broadleaf trees				
Cover (%)				
Pre-treatment	28.1	27.9	0.861	0.88
1 yr post-treatment	14.5	23.3	4.828	0.33
3 yr post-treatment	25.4	28.4	8.078	0.82
Height (cm)				
Pre-treatment	299.2	319.2	24.331	0.62
1 yr post-treatment	212.9	349.8	91.800	0.40
3 yr post-treatment	166.3	367.4	61.143	0.08*
Shrubs				
Cover (%)				
Pre-treatment	23.8	25.7	2.632	0.66
1 yr post-treatment	21.4	30.4	4.242	0.27
3 yr post-treatment	24.6	32.4	1.999	0.11
Height (cm)				
Pre-treatment	110.2	122.1	12.525	0.57
1 yr post-treatment	68.8	120.5	21.220	0.23
3 yr post-treatment	107.9	143.3	13.106	0.20
Herbs				
Cover (%)				
Pre-treatment	59.3	57.7	1.165	0.44
1 yr post-treatment	62.5	66.9	0.591	0.03*
3 yr post-treatment	61.7	58.2	3.759	0.57
Height (cm)				
Pre-treatment	28.9	28.1	1.321	0.70
1 yr post-treatment	32.8	27.8	4.445	0.51
3 yr post-treatment	31.7	36.8	7.770	0.69

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

[a] Treatment occurred over a 2-year period on one site.

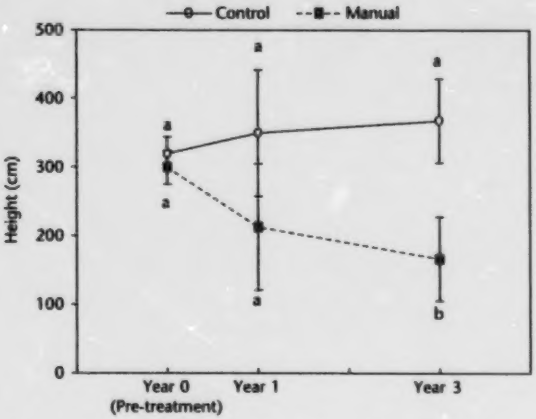


FIGURE 110 *Comparison of mean broadleaf height between the manual cutting treatment and control before, and 1 and 3 years after, treatment of the IDF/MS* Aspen *Complex. Error bars represent one standard error of the mean $(\bar{y})$ which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance $(\alpha = 0.10)$.*

TABLE 101 *Suckering characteristics of aspen in the IDF/MS* Aspen *Complex following manual cutting*[a]

Response variable	Mean
Proportion of stumps with suckers	
1 yr post-treatment	94
3 yr post-treatment	83
Number of suckers per stump	
1 yr post-treatment	4
3 yr post-treatment	3
Sucker length (cm)	
1 yr post-treatment	44
3 yr post-treatment	138

[a] Treatment occurred over a 2-year period on one site.

four suckers around each stump, and after 1 year, suckers averaged 44 cm in height. By year 3, 83% of cut aspen still had suckers, but they had thinned to an average of three per stump, and grown to an average height of 138 cm. Second- and third-year sucker growth rates averaged 47 cm/yr.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the *Aspen* Complex had no effect on either species richness or diversity within 3 years of treatment (p>0.10) (Table 102). Species richness increased slightly between the pre-treatment assessment (42 species) and the first-year assessment (46 species), and then decreased again in the third-year assessment (40 species). The changes occurred equally in the treatment and control, and were likely related to the timing of assessments.

Richness of structural vegetation groups did not differ between the treatment and control in either the first or third years after cutting (p>0.10) (Table 103). Diversity of structural vegetation groups was significantly lower in the brushing treatment than in the control in the first year after treatment (p = 0.06 for H, p = 0.05 for SDI), but the difference had disappeared by year 3. This reflects a large initial decrease in broadleaf cover because of the cutting treatment, followed by recovery through suckering.

Data for individual species were available for only two of the three replicate sites. As expected, manual cutting of the *Aspen* Complex resulted in immediate, large decreases in aspen cover on both sites. Most shrub and herb species occurred low in the understorey, and were affected little by the

TABLE 102 *Richness and diversity of vascular plant species in the IDF/MS* Aspen *Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Richness				
Pre-treatment	41.50	43.50	2.828	0.70
1 yr post-treatment	45.50	46.00	0.354	0.50
3 yr post-treatment	40.33	39.67	1.312	0.75
Shannon-Weaver Diversity Index				
Pre-treatment	2.33	2.37	0.150	0.89
1 yr post-treatment	2.41	2.50	0.218	0.83
3 yr post-treatment	2.23	2.22	0.107	0.97
Simpson's Diversity Index				
Pre-treatment	0.83	0.84	0.025	0.81
1 yr post-treatment	0.82	0.85	0.049	0.71
3 yr post-treatment	0.81	0.82	0.019	0.76

The standard error of the overall mean $(\bar{y})$ was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 103 *Richness and diversity of structural vegetation groups in the IDF/MS Aspen Complex before and after manual cutting in lodgepole pine plantations*

Response variable	Means: Manual cutting	Means: Control	Standard error	p-value
Richness				
Pre-treatment	6.50	6.00	0.354	0.50
1 yr post-treatment	6.50	6.00	0.354	0.50
3 yr post-treatment	6.33	6.33	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.40	1.49	0.011	0.11
1 yr post-treatment	1.25	1.46	0.013	0.06*
3 yr post-treatment	1.45	1.52	0.028	0.23
Simpson's Diversity Index				
Pre-treatment	0.70	0.74	0.001	0.03*
1 yr post-treatment	0.63	0.73	0.005	0.05*
3 yr post-treatment	0.72	0.75	0.012	0.25

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

cutting treatment. Exotic species of clover (*Trifolium* spp.) were present at the time of manual cutting, and their cover increased in the treatment within 1 year of brushing. There were no other changes in abundance of individual shrub or herb species across more than one site (Table 104).

Competition Thresholds

Competition thresholds were derived for stem diameter of lodgepole pine and Douglas-fir using all PROBE plantations dominated by the *Aspen* Complex. Most lodgepole pine sites occurred in the the IDFdk and MSdm subzones, and all Douglas-fir sites occurred in the ICHmw subzone (Table 97, Appendix 2). For lodgepole pine, the analysis included three sites that were manually cut, two that were treated with basal applications of triclopyr, and one where the aspen was cut and the sprouts sprayed with glyphosate (n = 6) (Table 105). For Douglas-fir, the analysis included two sites where aspen was manually cut and two where it was girdled (n = 4) (Table 106). The range in ages of Douglas-fir, lodgepole pine, and trembling aspen was 2–10, 2–10, and 5–11 years old, respectively. The competition thresholds were derived from total aspen cover (%), total aspen density (stems/ha), and CRH indices (CRH = (aspen cover * aspen modal height)/seedling height).

The competition thresholds for lodgepole pine stem diameter averaged 31% cover, 3180 stems/ha, and 31, using aspen cover, aspen density, and CRH as competition indices, respectively. The thresholds were sharp on most sites, where pine diameter decreased dramatically above the threshold values. Below the thresholds, pine diameter was highly variable across all competition indices (e.g., Figure 111). The proportion of trees that occurred above the thresholds was 45–59% of all trees (treated and control), 33–42% of control trees, and only 8–25% of treated trees. Most trees above the thresholds were control trees (60–90%), whereas most below the thresholds were treated trees (57–71%). Most treated trees (75–92%) were below the thresholds. These results suggest that brushing was moderately successful at reducing aspen density (see earlier density comments) below the thresholds for most treated pine, although many control pine (58–67%) also naturally occurred below the thresholds. As a result of improved competitive environments for

TABLE 104 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the IDF/MS Aspen Complex in lodgepole pine plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		*Populus tremuloides*	
Herbs	*Trifolium* spp.		*Taraxacum officinale* *Aster* spp.

most treated trees, mean diameter increment improved slightly in the treatment by year 3 ($p = 0.02$) (Table 99); however, the distribution of pine diameters across aspen neighbourhoods was relatively unchanged (e.g., Figure 111). In addition, only 3% of treated pine trees growing in neighbourhoods below the competition thresholds achieved ≥80% of the maximum diameter measured on the sites.

The competition thresholds for Douglas-fir stem diameter averaged 21% cover, 2400 stems/ha, and 19, using aspen cover, aspen density, and CRH as competition indices, respectively. The thresholds were sharp on two sites, where Douglas-fir diameter declined dramatically above the thresholds (e.g., Figure 112), but declined gradually on the other two (e.g., Figure 113). Fewer Douglas-fir than lodgepole pine occurred above the thresholds. The proportion of Douglas-fir that occurred above the thresholds was on average 20–30% of all trees (treated and control), 40–52% of control trees, and only 11–25% of treated trees. Most trees above the thresholds were control trees (78–81%), whereas most below the thresholds were treated trees (61–66%). Most treated trees (75–89%) were below the thresholds. These results suggest that brushing was moderately successful at reducing aspen abundance below the thresholds for most treated Douglas-fir. Douglas-fir diameter distributions appeared to improve following girdling and manual treatments; however, only 5% of treated trees achieved ≥80% of the maximum diameter measured on the sites. Unfortunately, there were not enough replicates to test for Douglas-fir diameter responses to either of these brushing treatments.

Linear regressions of lodgepole pine diameter versus competition index were statistically significant ($p<0.10$) on five of six sites for aspen cover, three of six sites for aspen density, and all sites for CRH (Table 105). The range in adjusted r^2 values was 0.16–0.42 for aspen cover, 0.07–0.28 for aspen density, and 0.22–0.45 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for aspen cover (-0.012 to -0.057), very shallow for aspen density (0 to -0.001), and moderately shallow for CRH (-0.001 to -0.024) compared with other complexes. For Douglas-fir, linear regressions were statistically significant on three sites for aspen cover and CRH, two sites for aspen density ($p<0.10$) (Table 106). The range in adjusted r^2 values was 0.21–0.37 for aspen cover, 0.08–0.26 for aspen density, and 0.35–0.39 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for aspen cover (-0.014 to -0.042), flat for aspen density (0), and very shallow for CRH (-0.002 to -0.009) compared with other complexes. Fitting a negative exponential function to the diameter-CRH relationships improved the adjusted r^2 values, from 0.35 to 0.41 for lodgepole pine site 27 (Table 105) and from 0.39 to 0.51 for Douglas-fir site 28 (Table 106). These results suggest that aspen cover and CRH are better indices than density for predicting lodgepole pine or Douglas-fir growth responses to competition. The cover regressions suggest that aspen competition was moderately important and moderately intense for both lodgepole pine and Douglas-fir.

TABLE 105 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting lodgepole pine stem diameter from the competition indices, aspen density, aspen cover, and CRH, in the Aspen Complex in the IDF/MS zones*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from aspen density[a]	Adjusted r^2 for linear regression predicting diameter from aspen density[a]	p-value for linear regression predicting diameter from aspen density[a]	Cover threshold (%)	Linear regression equation predicting diameter from aspen cover[a]
27	72	10	4800	$y = 4.074 - 0.000x$	0.00	0.66	40	$y = 5.587 - 0.028x$
40	67	2	1800	$y = 7.047 - 0.001x$	0.28	0.00	20	$y = 7.032 - 0.053x$
64	72	4	1700	$y = 1.479 - 0.000x$	0.09	0.01	25	$y = 1.709 - 0.012x$
66	72	7	n.d.	$y = 4.827 - 0.000x$	0.00	1.00	30	$y = 5.224 - 0.031x$
67	72	7	3900	$y = 6.532 - 0.000x$	0.00	0.94	40	$y = 6.663 - 0.006x$
77	70	3	3700	$y = 8.172 - 0.000x$	0.07	0.02	30	$y = 8.805 - 0.057x$
mean			3180				31 (3)	
(s.e.)			(560)					

TABLE 106 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Douglas-fir stem diameter from the competition indices, aspen density, aspen cover, and CRH, in the Aspen Complex in the ICH zone*

Site	Conifer age (yr)	Density threshold (stems/ha)	Linear regression equation predicting diameter from aspen density[a]	Adjusted r^2 for linear regression predicting diameter from aspen density[a]	p-value for linear regression predicting diameter from aspen density[a]	Cover threshold (%)	Linear regression equation predicting diameter from aspen cover[a]
28	10	3500	$y = 5.443 - 0.000x$	0.26	0.00	20	$y = 5.824 - 0.042x$
52	2	1500	$y = 1.930 - 0.000x$	0.00	0.43	10	$y = 2.420 - 0.014x$
74	4	2800	$y = 3.806 - 0.000x$	0.08	0.01	10	$y = 4.100 - 0.019x$
100	7	1800	$y = 10.082 - 0.000x$	0.00	0.80	45	$y = 9.78 - 0.008x$
mean		2400				21 (8)	
(s.e.)		(460)					

TABLE 105 *Continued*

Adjusted r^2 for linear regression predicting diameter from aspen cover[a]	p-value for linear regression predicting diameter from aspen cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
0.16	0.00	32	$y = 4.969 - 0.010\,x$	0.35	0.00	$y = 5.349\,e^{(-0.004 * x)}$	0.41
0.42	0.00	10	$y = 6.798 - 0.021\,x$	0.45	0.00		
0.28	0.00	51	$y = 1.561 - 0.001\,x$	0.44	0.00		
0.16	0.00	19	$y = 5.123 - 0.021\,x$	0.22	0.00		
0.00	0.61	30	$y = 6.870 - 0.015\,x$	0.04	0.05		
0.22	0.00	42	$y = 8.618 - 0.024\,x$	0.27	0.00		
		31 (6)					

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[a] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is aspen cover or density, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (aspen cover * aspen modal height)/pine total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

TABLE 106 *Continued*

Adjusted r^2 for linear regression predicting diameter from aspen cover[a]	p-value for linear regression predicting diameter from aspen cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
0.37	0.00	10	$y = 5.573 - 0.007\,x$	0.39	0.00	$y = 6.176\,e^{(-0.003 * x)}$	0.51
0.21	0.00	20	$y = 2.259 - 0.002\,x$	0.36	0.00		
0.26	0.00	25	$y = 4.116 - 0.009\,x$	0.35	0.00		
0.00	0.86	20	$y = 10.283 - 0.020\,x$	0.01	0.27		
		19 (3)					

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[a] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is aspen cover or density, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (aspen cover * aspen modal height)/Douglas-fir total height.

[c] General form of non-linear equation is: $y = a\,e^{(b\,x)}$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the shape parameter.

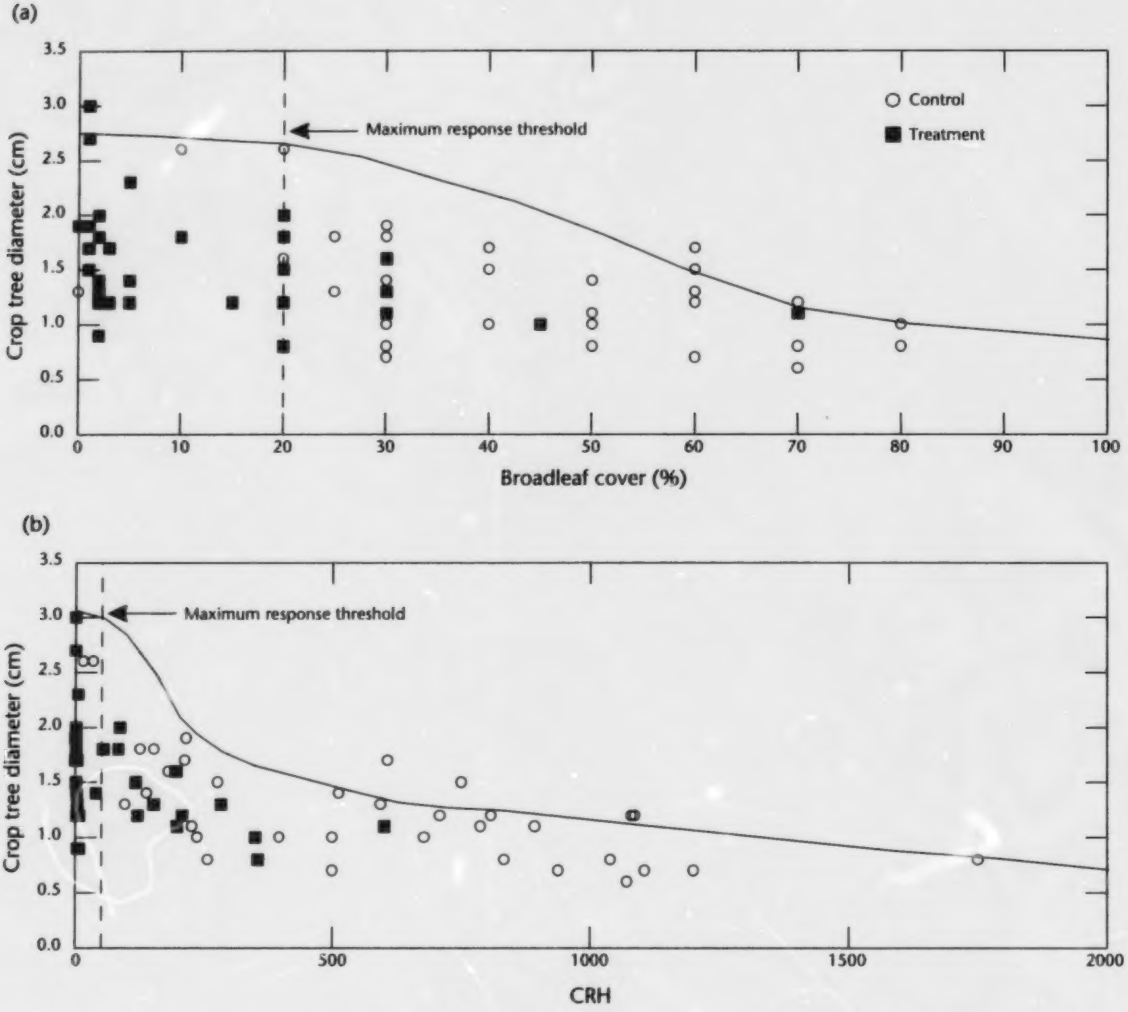

FIGURE 111 *Relationship between stem diameter of lodgepole pine growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/pine height. Data points include both treatment and control subplots for PROBE site 40 (n = 67). Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

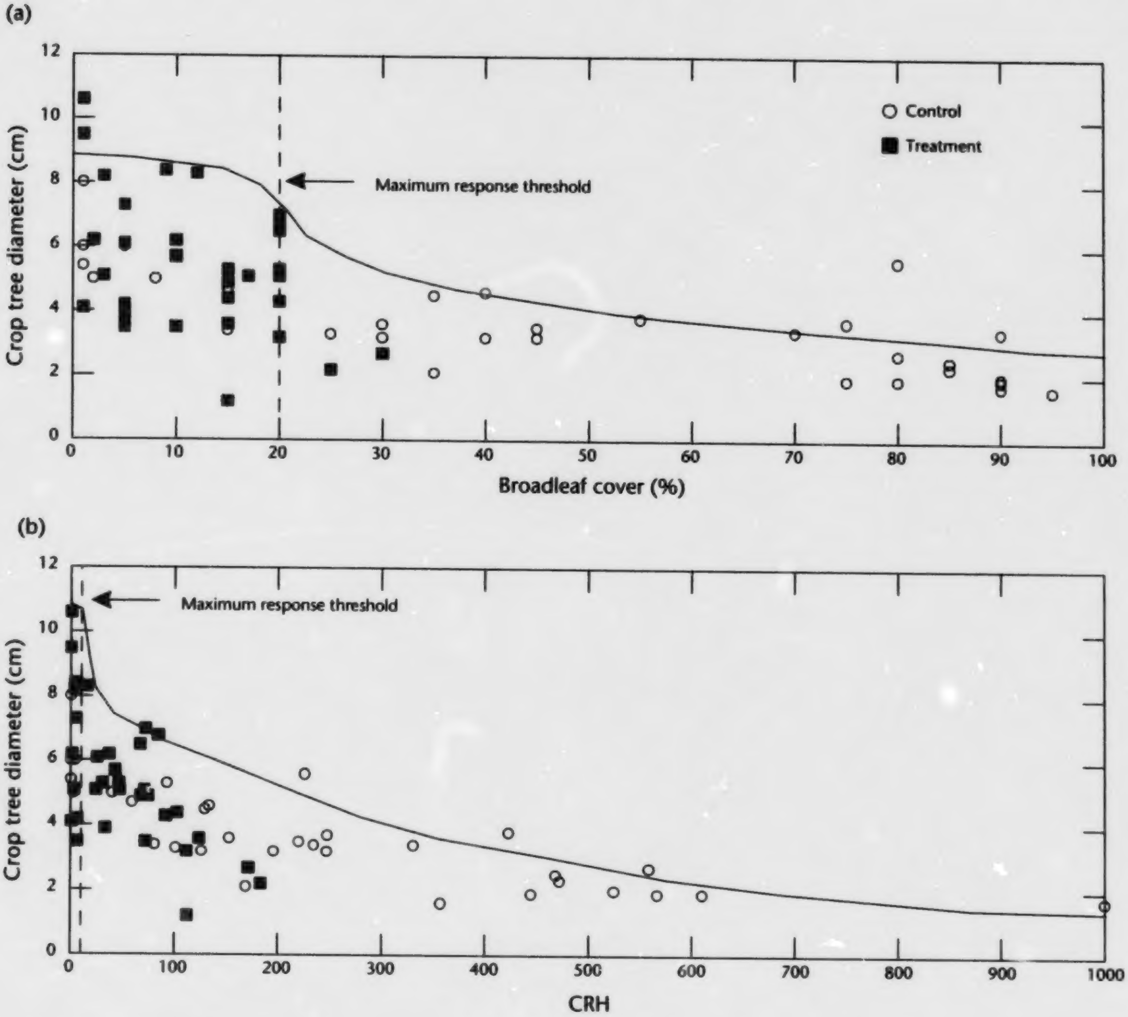

FIGURE 112 *Relationship between stem diameter of Douglas-fir growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 28 (n = 65) where the thresholds are sharp. Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

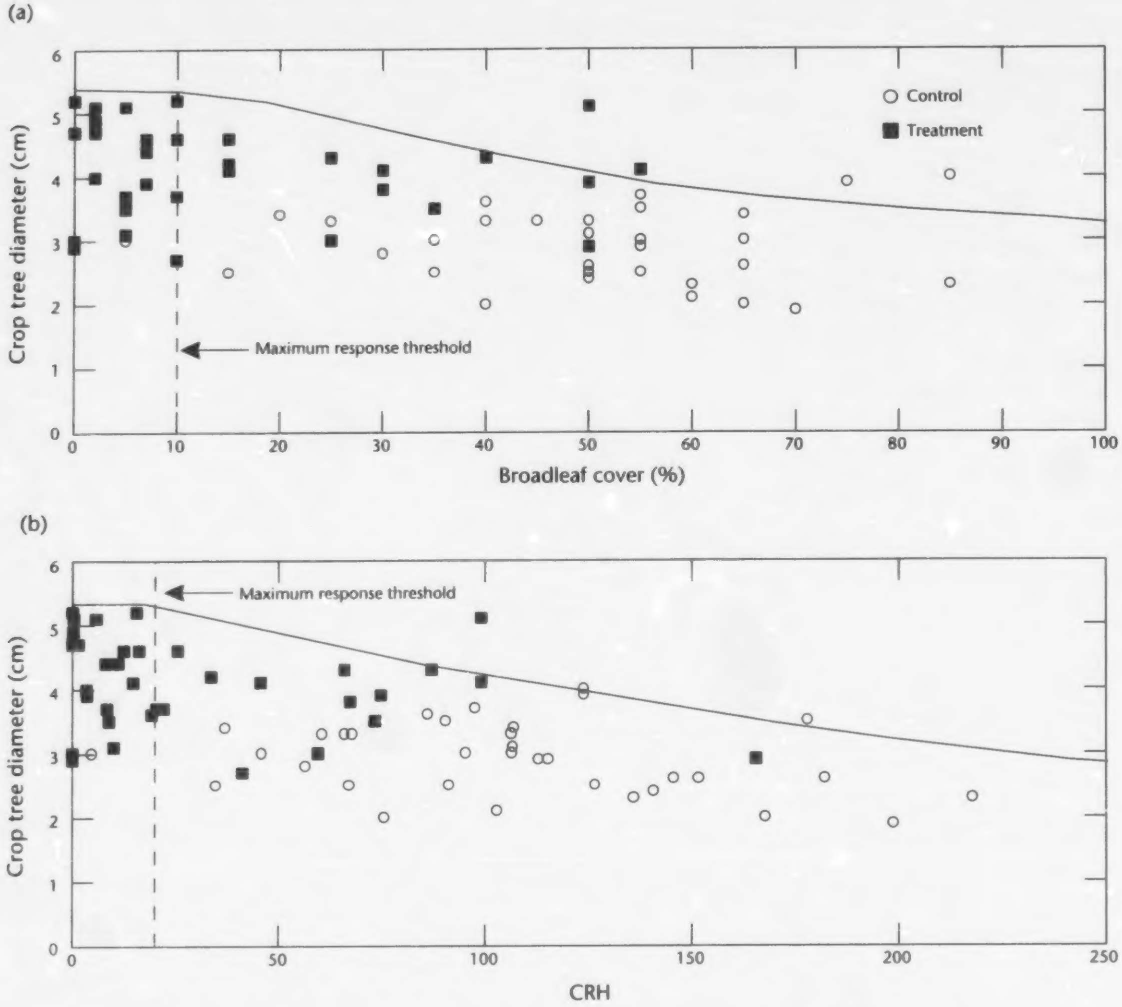

FIGURE 113 *Relationship between stem diameter of Douglas-fir growing amongst the IDF/MS Aspen Complex and (a) broadleaf cover or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 52 (n = 71) where the thresholds are vague. Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

Conifer Responses

Three years after manual cutting was applied in our study, 100% of lodgepole pine seedlings survived in both the treatment and control. We anticipated high rates of survival because seedlings were well established (7–10 years old) and healthy when brushing took place. Silviculture survey information suggests that a small amount of mortality occurred prior to brushing, and it is possible that survival could have been affected by brushing if it were done when seedlings were younger. However, target stocking was met on our sites, and improving survival was not a necessary management objective. Newsome (1999) found that removing aspen in at least a 1-m radius around seedlings reduced cover for voles and improved pine survival by year 5.

Aspen is less susceptible than conifers to *Armillaria* root disease (Peterson and Peterson 1995), and its presence may help reduce the spread of root rot. There was no *Armillaria*-related mortality in our study, however, and where it did occur in unreplicated brushing treatments, it appeared to be equally prevalent in the treatment and control. In contrast, our *Mixed Broadleaf-Shrub* results (Section 11) indicate that the removal of birch, which is also resistant, can increase the proportion of conifers killed by *Armillaria*. Whipping from aspen branches is also a common form of conifer damage associated with the *Aspen* Complex (Lees 1966; Newsome 1997), but none was recorded in our study.

Three years after the *Aspen* Complex was manually brushed, pine were growing slightly faster in stem diameter but slower in height (leader length) in the cutting treatment than in the control. Therefore, height:diameter ratio was lower in the treatment (56) than in the control (66). This suggests that treated seedlings were becoming sturdier while those in the control were becoming more spindly. Newsome (1999) also found that height:diameter ratio of 5-year-old lodgepole pine was lower in the treatment (56), where all aspen had been removed, than in the control (65). She predicts that reduced aspen densities in the treated area will eventually result in improved pine growth. By contrast, we doubt that the minor improvement in stem diameter increment measured in our study will result in biologically significant increases in growth over the long term. Pine in the control were healthy in our study, even though they were shorter than the surrounding aspen. Our unreplicated results for basal application of triclopyr suggest that pine responds well to that treatment (unpublished data; Appendix 2).

We have not yet studied spruce responses to brushing in the *Aspen* Complex, but there has been considerable research in northern ecosystems. Lees (1966) found that removing aspen growing in close proximity to understorey spruce improved diameter and height of the conifers across a wide range of age classes. In Manitoba and Saskatchewan, stem diameter of 15- to 40-year-old white spruce improved by up to 177% following removal of an aspen overstorey (Yang 1989). In our study, lodgepole pine growth responses were relatively small. This is possibly because both conifers and aspen were relatively young, and because aspen were smaller relative to conifers, compared with other studies. In our unreplicated girdling and manual cutting treatments, Douglas-fir appeared to increase in stem diameter 3–5 years after brushing treatments were applied to the *Aspen* Complex (Mather and Simard 1997a, 1998l; Appendix 2). Responses may vary among conifer species because of differences in their phenotypic plasticity.

Plant Community Responses

Significant reductions in overall broadleaf abundance did not occur until 3 years after PROBE initiation because treatment application was spread over 2 years on one of the sites. At that site, small stems were cut 1 year and large stems were girdled the next, resulting in a decrease in broadleaf height between years 1 and 3. Reductions in cover and height of aspen alone (i.e., excluding other broadleaf species) were not significant because of variability among sites, but aspen averaged 62% shorter in the treatment (194.4 cm) than in the control (509.5 cm) 3 years after cutting. Hart and Comeau (1992) concluded that manual cutting was not particularly effective for controlling aspen because of the rapid growth of suckers. However, in our study, cutting successfully reduced aspen height below that of lodgepole pine during the 3-year measurement period.

Suckers occurred in close proximity to most aspen stumps on the study sites, and they grew to a height of 44 cm in the first year. This was slightly less than the average first-year height (0.5–1.0 m) reported for the Salmon Arm District (Haeussler et al. 1990) and substantially less than that (1.5–3 m) reported by Peterson and Peterson (1995). The lower growth rate in this study was partly due to cattle grazing on one of the sites. Opinions vary regarding the most effective time to cut aspen, but sucker production generally appears to be reduced when treatment occurs during the growing season (Haeussler et al. 1990). In our study, aspen was cut in July on one site and September on the other two sites.

Our preliminary results for aspen girdling (Mather and Simard 1998l; Appendix 1), as well as other sources (Haeussler et al. 1990; Hart and Comeau 1992), suggest that girdling reduces aspen vigour and minimizes suckering, even though it takes 1–3 years for the full impact of treatment to be expressed. Preliminary results for basal triclopyr application suggest that both cover and height of aspen are reduced and suckering eliminated (unpublished data; Appendix 2). These findings agree with those of Biring et al. (1996).

Cutting aspen did not stimulate the low shrub and herb layers to increase in abundance. In fact, herb cover decreased slightly in the first year after cutting, probably because it was pressed down by the aspen slash. Cutting had no effect on richness or diversity of vascular plant species. Haeussler (1999) also found that most silviculture treatments, including manual cutting, tended not to affect diversity. Manual cutting had no lasting effect on richness or diversity of the structural vegetation groups. This is an important consideration for wildlife because aspen use changes according to the successional stage of the stand; mammals use it prominently in young stands (<20 years old), and bird populations use it increasingly as stands age (Peterson and Peterson 1995). The aspen stands were only 7–10 years old at the time of cutting, and the treatment may have temporarily increased abundance of summer forage (young suckers) and decreased both winter forage and cover for large animals. Cattle traffic increased in the first year after cutting, suggesting that they were grazing the new aspen suckers. Aspen suckers are preferred forage for cattle (DeByle and Winokur 1985) and sheep, although slash from cutting can impede their access (Newsome et al. 1995).

Effects of the Community on Resource Availability

Little information is available on mechanisms of aspen competition, but it is thought to hinder conifer seedling performance throughout interior British Columbia, mainly by intercepting light. However, the intensity of light competition may be greater in northern ecosystems, where aspen stands tend to be dense, than in the southern interior, where they are more open (P. Comeau, pers. comm., 1999). For instance, Mather (1988) found that aspen cover in wetter ICH subzones in the southern interior rarely exceeded 10% cover within 15 years of site disturbance. In our study, aspen averaged 26% cover, and understorey conifers were healthy and growing well. In north-central British Columbia and Alberta, mature aspen canopies were found to transmit 7–36% (DeLong et al., [2000]) and 14–40% (Lieffers and Stadt 1994) of full light, respectively. Rapidly growing, early seral aspen may compete more strongly for light than maturing aspen, particularly if it is of vegetative origin. This is because sucker-origin stands can be dense prior to self-thinning (Jones 1976; Crouch 1983; Bella 1986), and the trees often have large leaves compared with older, or seed-origin aspen (T. Newsome, pers. comm., 2000; J. Wright, pers. comm., 2000). In addition, the dense canopies of juvenile aspen stands are similar in height to understorey conifers, which reduces the incidence of oblique and reflective light compared with mature aspen stands. Brushing treatments are usually applied to aspen that has established post-logging, and that is therefore of similar age to the conifer seedlings. Treatments vary in how rapidly they increase light availability to seedlings. Girdling increases light gradually because aspen dies slowly following treatment (Hart and Comeau 1992), whereas manual cutting and chemical treatments cause more rapid increases in light availability.

Aspen may also compete with conifers for water on drier sites. Aspen crowns are thin on dry sites, suggesting that light may be less important to seedling growth than soil water (T. Newsome, pers. comm., 2000). Aspen also develop obliquely descending lateral roots that increase access to deep sources of soil water (Strong and La Roi 1983), suggesting an adaptation to dry sites. DeLong and Tanner (1996) found that, in northern ecosystems, aspen can reduce both light and soil water to levels that could limit conifer seedling growth for at least part of the growing season. Some of the understorey species associated with the *Aspen* Complex on dry sites may also contribute to soil water competition with conifer seedlings. Pinegrass, in particular, is a strong competitor for soil water (Petersen and Maxwell 1987; Nicholson 1989).

Aspen provides a number of benefits to conifers. Aspen canopies can improve the thermal environment for young seedlings in comparison with clearcuts. DeLong et al. (2000) found a much lower incidence of frost damage among spruce seedlings planted under a 40- to 80-year-old aspen canopy than those planted in a clearcut and suggested that it was a result of reduced radiative heat loss. However, young aspen are less likely to protect conifer seedlings from frost damage because low canopies are variable in their effects on air temperature at seedling height (Stathers 1989). Studies that have focused on regenerating white spruce in northern ecosystems have concluded that milder soil and air temperatures under aspen canopies are conducive to juvenile spruce growth, but that continued growth is better in the open (Kabzems and Lousier 1992; DeLong et al. 2000). Low soil temperature is not an important growth-limiting factor in southern interior biogeoclimatic zones where the *Aspen* Complex is common (e.g., ICH, IDF, MS), but it likely increases in importance in more northern ecosystems.

Aspen provides both short- and long-term nutritional benefits to forest sites. It takes up large quantities of nutrients and stores them in woody tissues, thus retaining nutrients within the ecosystem. It is particularly efficient at retaining calcium, sulfur, and zinc, especially in the bark, which has photosynthetic capability (Pearson and Lawrence 1958). Aspen foliage is shed annually, but it decomposes rapidly (Prescott et al. 2000) and tends to be efficiently cycled within the forest system (Pastor 1990). A modelling study based on data collected in boreal forests of northeastern British Columbia suggests that mixed forests of aspen and spruce will produce greater biomass over several rotations than pure spruce forests of the same density (Wang, Comeau, and Kimmins 1995).

Competition Thresholds

The competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for aspen density, 31 and 21% for aspen cover, and 31 and 19 for CRH, respectively. Above the thresholds, aspen competition appeared to be the most important factor limiting conifer growth, setting an upper limit for conifer stem diameter. About half the lodgepole pine (45–59%) and a smaller proportion of Douglas-fir (20–30%) control and treated trees were growing in aspen neighbourhoods above these thresholds, which suggests that competition was constraining more trees in the lodgepole pine than the Douglas-fir plantations. Brushing left only 8–25% of treated lodgepole pine or Douglas-fir trees in neighbourhoods above the thresholds, indicating that brushing should have released most suppressed trees. However, 29–43% of control trees naturally occurred below the thresholds, which suggests that a large portion of trees would not benefit from brushing. Below the thresholds, stem diameter was highly variable among both treated and control trees. Very few (3–5%) trees were able to achieve greater (≥80% of the site maximums) growth, and most appeared to be limited by other factors.

The regression analyses showed that the three aspen competition indices explained at best 39–51% of the variation in lodgepole pine or Douglas-fir stem diameter. The importance of competition in the *Aspen* Complex to conifer performance, as expressed by adjusted r^2 values, was similar to that measured in our *Mixed Broadleaf-Shrub* Complex (this publication) as well as aspen stands in south-central British Columbia (Newsome 1997, 1999) and northern Alberta (Navratil and MacIsaac 1996). The moderate predictive ability of the regression models, the wide variability in conifer performance at low-moderate aspen competition levels, as well as the low proportion of conifers constrained by detrimental broadleaf levels (i.e., above the thresholds), in combination, suggest that the diameter of many trees in the plantations may not improve following broadcast brushing treatments. They also suggest that aspen competition was only one of several factors affecting conifer growth in the plantations, and that brushing will not necessarily alleviate the most important limitation to growth for many trees, except for those growing among high aspen densities. Indeed, we found that neither average stem diameter nor diameter distributions of lodgepole pine improved 3 years following broadcast manual treatments of aspen. However, pine diameter increment improved slightly, suggesting that there may be a delayed diameter response. Newsome (1999) also found no effect of competition from suckering aspen on lodgepole pine diameter 5 years after clearing, preparing, and planting lodgepole pine on a 15-year-old aspen site that was allowed to regenerate to a range of aspen competition levels. However, aspen was still young at that assessment, and its competitive effect on pine was expected to increase with time (T. Newsome, pers. comm., 2000). The long-term effects of aspen removal on pine yield are unknown, but simulations with the FORECAST ecosystem simulation model showed that variation in initial aspen densities had little effect on white spruce stemwood biomass over a 120-year rotation (Wang, Comeau, and Kimmins 1995).

The aspen density thresholds identified for lodgepole pine in our study generally agree with those of other studies. In the Cariboo Forest Region, lodgepole pine stem diameter growth did not decrease significantly until aspen density within a 1.8-m radius exceeded 2000 stems/ha in the IDFdk3/4 and SBSdw1 variants (Newsome 1997, 1999). Our threshold for pine (3180 stems/ha) in the IDFdk2 variant differed for several possible reasons. Firstly, our threshold included all aspen neighbours, whereas Newsome (1997, 1999) included only those aspen taller than target lodgepole pine, which have been shown to be the strongest competitors with spruce and pine (Navratil and MacIsaac 1993, 1996; Newsome 1997, 1999). The young aspen stands in our study (4–11 years old) were structurally complex with strongly left-skewed height distributions, and had approximately six times as many shorter than taller aspen stems/ha (data not shown). The inclusion of all aspen sizes would therefore result in higher thresholds. Because of the strong skew in aspen height distributions, and the lower competitive effect of shorter versus taller aspen, it is possible that a density threshold based only on taller aspen in our stands may be even lower than that of Newsome (1999). Secondly, aspen thresholds were based on 3.99-m-radius neighbourhood plots in our study and 1.8-m plots in Newsome (1997, 1999). Competitive effects have been shown to decrease with distance (Harper 1977; Simard 1990a), and consequently, pine would tolerate a greater density of aspen >1.8 m than <1.8 m distant. Thirdly, the IDFdk2 sites in our study are climatically warmer and slightly wetter than the IDFdk3/4 sites (Steen and Coupé 1997; Lloyd et al. 1990) in Newsome (1999). Broadleaf threshold densities for conifer growth have been shown in other studies to decrease with site productivity (Simard 1990a, 1990b). If thresholds based on taller aspen are indeed lower in our study than in Newsome (1999), as suggested above, then relations with site productivity follow the findings of Simard (1990a, 1990b).

The aspen cover thresholds are similar to those identified in 5- to 16-year-old lodgepole pine–aspen stands in northern Alberta (Navratil and MacIsaac 1996). Lodgepole pine diameter did not decline until aspen cover exceeded 31% in our study, compared with approximately 20% in Navratil and MacIsaac (1996). Our thresholds may be higher because we used total aspen cover, whereas Navratil and MacIsaac (1996) used cover over the top one-third of the target pine tree. Site characteristics also varied considerably between these studies, and others have suggested that competition thresholds vary with site conditions (Simard 1990a; Simard 2001, in review). Competition indices other than aspen density or cover have been successfully applied to pine–aspen stands. For example, Navratil and MacIsaac (1993) found that basal diameter (BD) ratio (tallest aspen basal diameter divided by pine basal diameter) and Lorimer's competition index (aspen basal diameter divided by pine basal diameter) were much better correlated with pine diameter and height than were aspen cover or density indices. Using these indices, they found that aspen within a 1.8-m radius with a BD ratio >0.75 resulted in sharp reductions in pine diameter growth.

Aspen competition thresholds were considerably lower for Douglas-fir growing in the ICHmw subzone than for lodgepole pine in the IDFdk and MSdm subzones. There are three possible explanations for these differences. Firstly, lodgepole pine is more plastic in its growth response to varying light intensities than most other British Columbia conifer species (Coates and Burton 1999) and may therefore grow well under a wider range of aspen densities. Secondly, the ICHmw subzone is considerably wetter and more productive than the IDFdk or MSdm subzones (Lloyd et al. 1990), and broadleaf density thresholds have been shown to decrease with increasing site productivity (Simard 1990b). This may be due to greater individual growth rates and faster self-thinning among broadleaf neighbours on more productive sites, resulting in fewer neighbours of similar or greater competitive effect compared with less productive sites. In the ICH zone, aspen grows very quickly and rapidly overtops conifers, whereas, in the drier zones, aspen grows more slowly and is less competitive with conifers. Thirdly, temperature extremes are greater in the IDFdk and MSdm than in the ICHmw subzone (Lloyd et al. 1990), and greater aspen cover may be necessary to protect conifers against growth-inhibiting frosts or vapour pressure deficits (Stathers 1989).

Effectiveness of Treatment at Meeting Management Objectives

Common management objectives for brushing the *Aspen* Complex are both to improve conifer seedling growth and to help meet free-growing requirements. In this study, lodgepole pine were well established at the time of brushing, and improving survival was not an objective. We measured minor improvements in pine growth as a result of applying manual cutting treatments to the *Aspen* Complex, but further monitoring is necessary to determine whether the differences eventually become biologically and economically significant. Pine in both the treatment and control were increasing in height at adequate rates according to Vyse and Navratil (1985), but the cutting treatment will likely prove to be necessary for control seedlings to meet the conifer:vegetation height ratio requirement for free-growing.

For our IDF study sites, the old free-growing guidelines (B.C. Ministry of Forests 1995a) specified target stocking of 1000 (minimum 500) well-spaced stems/ha, and required that, 12–15 years after logging, pine must be a minimum of 1.0 m tall and 125% as tall as neighbouring vegetation. For the MS site, it specified target stocking of 1200 (minimum 700) well-spaced stems/ha, and required that, 9–15 years after logging, pine must be a minimum of 1.0 m tall and 125% as tall as neighbouring vegetation. The new free-growing guidelines (B.C. Ministry of Forests 2000) allow broadleaf height to exceed that of conifers in one of four quadrants of the assessment radius, and allows the retention of 1000 broadleaf stems/ha on the IDF sites and 400 broadleaf stems/ha on the MS sites. Our sites have not been surveyed according to the new guidelines, but 3 years after brushing, when pine were 10–13 years old, those in the manual cutting treatment met all of the old free-growing requirements within the assessment window. Control pine met minimum height and stocking requirements, but averaged only 89% as tall as surrounding vegetation. Because pine were increasing in height (39 cm/yr) more slowly than aspen (69 cm/yr), those in the control were not expected to meet the conifer:vegetation height ratio requirement within the free-growing window (Figure 114). Also, although we did not assess the density of broadleaves that were taller than conifers, modal height and cover observations suggest the allowable density specified in the new free-growing guidelines (B.C. Ministry of Forests 2000) would be exceeded.

Management objectives for the *Aspen* Complex are currently in a state of flux because of increasing utilization of aspen (Peterson and Peterson 1995) and increasing interest in managing mixedwood stands to maintain diversity and long-term site productivity (Wang, Comeau, and Kimmins 1995). In addition, silviculture and range objectives for the *Aspen* Complex often conflict. It is important to identify competition thresholds for this community to avoid unnecessary brushing treatments.

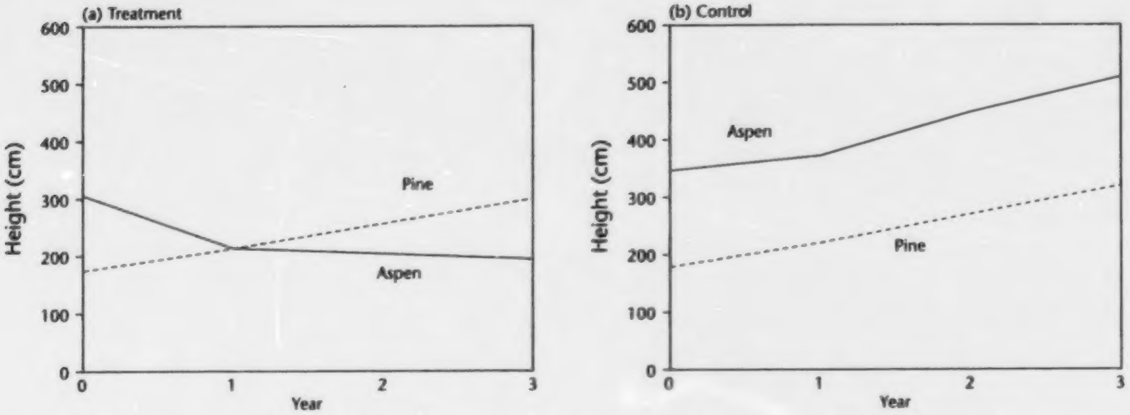

FIGURE 114 *Comparison of average lodgepole pine and aspen height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the IDF/MS* Aspen Complex. *Height for year 2 is interpolated from actual data. Treated pine outgrew broadleaves 1 year after manual cutting, whereas control pine are expected to remain below the aspen canopy through the free-growing assessment window.*

CONCLUSIONS

In our study, applying manual cutting to the *Aspen* Complex appears to have allowed lodgepole pine that were 7–10 years old at the time of treatment to meet all the requirements for free-growing (B.C. Ministry of Forests 2000), whereas untreated seedlings were not expected to do so. The cutting treatment resulted in minor improvements in lodgepole pine diameter growth within 3 years of brushing, but control seedlings were also healthy and growing well. Increases in seedling growth were small, and preliminary findings suggest that there may be no long-term growth and yield benefits. However, further monitoring is required to confirm this. Brushing had no effect on the richness or diversity of vascular plant species, and only a minor, short-lived effect on the diversity of structural vegetation groups. Competition thresholds were identified for lodgepole pine and Douglas-fir using aspen density, aspen cover, and CRH indices; however, regressions explained at best 39–51% of the variation in conifer stem diameter.

MANAGEMENT IMPLICATIONS

1. Our results suggest that brushing is not required to maintain good survival and health of established lodgepole pine (7–10 years old) growing among moderate cover of aspen (average 26%) in the IDF and MS subzones of the southern interior.
2. On our study sites, lodgepole pine growing among the *Aspen* Complex are not expected to meet the new free-growing requirements without intervention (B.C. Ministry of Forests 2000). Minimum seedling height and stocking standards may be met, but not the conifer:vegetation height ratio requirement. Our results suggest that manual cutting can reduce aspen height sufficiently to create free-growing stands. However, reducing aspen abundance does not appear to generate a large conifer growth response.
3. Minor improvements in lodgepole pine diameter growth are likely to occur as a result of reducing abundance of the *Aspen* Complex through manual cutting. However, we are uncertain whether these increases will affect yield at rotation. Other studies, mainly in northern ecosystems, show larger seedling growth increases following brushing in the *Aspen* Complex.
4. Competition thresholds for stem diameter of lodgepole pine and Douglas-fir averaged 3180 and 2400 stems/ha for aspen density, 31 and 21% for aspen cover, and 31 and 19 for CRH, respectively, where all-sized aspen were used in the analysis. These thresholds are comparable to those reported in other studies.
5. Applying manual cutting treatments to the *Aspen* Complex is likely to have no effect on richness or diversity of individual vascular plant species. Changes in the diversity of structural vegetation groups may occur, but are expected to be short-lived.

SECTION 11

Mixed Broadleaf-Shrub Complex

ABSTRACT

We have fifth-year results demonstrating the effects of manual cutting, girdling, and cut stump–glyphosate treatments on the *Mixed Broadleaf-Shrub* Complex and conifers in the ICH and IDF zones. Manual cutting was applied in 5- to 8-year-old Douglas-fir and 3- to 10-year-old lodgepole pine plantations, girdling was applied in 5- to 17-year-old Douglas-fir plantations, and cut stump–glyphosate treatment was applied in 8- to 9-year-old Douglas-fir plantations.

Manual cutting: Cutting reduced broadleaf height for at least 5 years, but the effects on cover were not significant because of vigorous sprouting. After 5 years, broadleaves had recovered to about half the control height, and were taller than Douglas-fir but not lodgepole pine. The cutting treatment was not needed to ensure good survival of Douglas-fir or lodgepole pine and, to the contrary, caused an increase in pine mortality from *Armillaria* (7% in the treatment versus 2% in the control in year 3, $p = 0.07$). Five years after brushing, Douglas-fir stem diameter averaged 14% greater and leader lengths were 9.6 cm longer in the treatment than in the control, but height had not improved significantly. Lodgepole pine stem diameter increased by 37% as a result of cutting, and height:diameter ratio was significantly lower in the treatment (56.0) than in the control (68.5). Total height and leader length of pine were unaffected by the manual cutting treatment after 5 years. Manual cutting had no effect on vascular plant species richness or diversity.

Girdling: Girdling killed almost all broadleaves, but modal height was unaffected during the 5-year measurement period because treated stems died gradually and some stems were missed during treatment. Large reductions in broadleaf cover were significant only in the first year after girdling because of great variability among sites. Girdling caused a significant reduction in Douglas-fir survival during the 5-year measurement period (90% in the treatment versus 97% in the control), mainly because *Armillaria* caused significantly more mortality in the girdling treatment than in the control (8 versus 3%, $p = 0.07$). Girdling increased Douglas-fir leader length by 56%, but had no effect on stem diameter or height. However, seedling responses may be somewhat delayed in the girdling treatment because of the gradual mortality of broadleaves. Girdling had no effect on species richness but resulted in a small, short-lived increase in diversity.

Cut stump–glyphosate: Cut stump–glyphosate treatment had a more severe effect on broadleaf abundance than either manual cutting or girdling. After 5 years, broadleaf height and cover in the treatment were less than one-half and one-quarter, respectively, of control values. Survival of Douglas-fir was excellent (average 95%) in both the cut stump–glyphosate treatment and control, and mortality caused by *Armillaria* was unaffected. However, the percentage of poor-vigour trees increased from 11 to 39% in the control while remaining constant in the girdled area. Five years after treatment, average Douglas-fir stem diameter was 52% (2.63 cm) greater in the brushed area than in the control and average height was 25% (79.9 cm) greater. Cut stump–glyphosate treatment had no effect on vascular species richness or diversity.

Competition thresholds for stem diameter of Douglas-fir, lodgepole pine, and interior spruce averaged 3664, 3367, and 2500 stems/ha for

broadleaf density, 28, 18, and 20% for broadleaf cover, and 39, 15, and 27 for CRH (broadleaf cover * broadleaf modal height)/conifer height, respectively, where all-sized broadleaves were used in the threshold estimates. Our density thresholds agree with those estimated by Simard (2001, in review).

Without treatment, our results suggest conifer stands growing in the *Mixed Broadleaf-Shrub* Complex generally will not meet all of the free-growing requirements within the recommended window (B.C. Ministry of Forests 2000). In particular the conifer:vegetation height ratio requirement is unlikely to be met.

Description of the *Mixed Broadleaf-Shrub* Complex

The *Mixed Broadleaf-Shrub* Complex is characterized by the three broadleaf species that are common in southern interior British Columbia: paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and black cottonwood (*Populus trichocarpa*). Birch is dominant, but mixtures of two or all three of the species are common. Willow (*Salix* spp.) and/or Sitka alder (*Alnus viridis*) sometimes occur in the mid-storey, and thimbleberry (*Rubus parviflorus*) and fireweed (*Epilobium angustifolium*) are common in the understorey (Figure 115). On sites where aspen dominates, the vegetation community is referred to as the *Aspen* Complex (described in Section 10), and if cottonwood is dominant, it is classified as the *Cottonwood-Shrub* Complex. Broadleaf stands in southern interior British Columbia tend to be dominated by birch in wet climatic regions and aspen where it is drier (Lloyd et al. 1990).

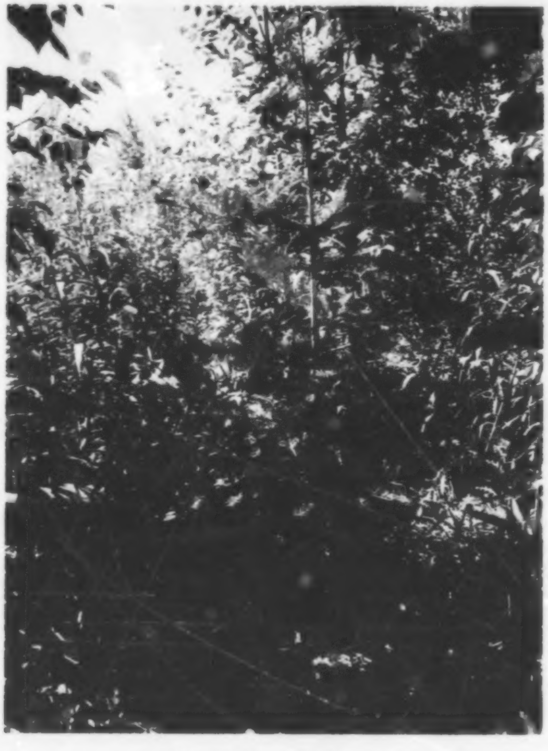

FIGURE 115 *The* Mixed Broadleaf-Shrub *Complex and Douglas-fir prior to manual cutting at Johnson Lake (Site 29) in the ICHmk1 variant in the Kamloops Forest District. Photo credit: Jean Mather.*

The *Mixed Broadleaf-Shrub* Complex is most widespread in the ICH zone, which covers over 3 million hectares in British Columbia. In the southern interior, the complex is also common in wet-belt portions of the IDF zone, and sometimes the MS zone. Birch has an exceptionally wide distribution in British Columbia and the *Mixed Broadleaf-Shrub* Complex can be found in all biogeoclimatic zones except the MH and AT (Peterson et al. 1997).

Development of the *Mixed Broadleaf-Shrub* Complex

Birch is the dominant species associated with the *Mixed Broadleaf-Shrub* Complex, and is therefore the focus of this section. Aspen tends to occur in patches in the *Mixed Broadleaf-Shrub* Complex, particularly on sites where mature stems were present in the original stand and produced suckers following harvesting. Aspen autecology and development are discussed in detail in Section 10 of this report. Cottonwood tends to be present in the complex on sites where seed and suitable seedbeds are available; compacted skid roads and areas with moist, completely exposed mineral soil are particularly desirable (Simard and Vyse 1992).

Birch is shade-intolerant (Hosie 1969), and it expresses its best growth on open sites with moist, well-drained sandy loam or silty-textured soils, or on soils derived from limestone (Peterson et al. 1997). It has moderately high requirements for nitrogen, calcium, and magnesium, and prefers medium to rich sites (Krajina et al. 1982). Young birch trees tolerate a wide range of environmental conditions, making them efficient competitors for resources; they are moderately tolerant of drought stress (Ranney et al. 1991) and can tolerate high summer temperatures if sufficient soil water is available (Simard and Vyse 1992). They are also very frost-resistant, and can begin spring growth well before conifers, when temperatures are below freezing (Fowells 1965; Krajina et al. 1982; Peterson et al. 1997).

Paper birch reproduces mainly from seed (Fowells 1965), although it can also reproduce vegetatively from sprouting of cut or damaged stems (Hosie 1969; Klinka and Scagel 1984). It produces abundant seed, beginning at about age 15 years and peaking at age 40–70 years. Most seed falls within 100 m of parent trees, but it is light and readily blown for greater distances, especially over snow (Burns and Honkala 1990). Most birch seed germinates immediately after snowmelt in the first spring after it is shed (Haeussler et al. 1990). Germination is most abundant on moist, shady seedbeds of mineral soil or mixed mineral-organic material (Marquis et al. 1964; Marquis 1966).

In spite of germinating best in shade, birch requires abundant light for continued growth (Marquis et al. 1964) and rarely survives under established forests except in openings created by windthrow, insects, or disease (Burns and Honkala 1990). Birch reproduction is therefore most favoured by disturbances that remove the forest canopy to increase light (e.g., harvesting or wildfire), and that expose mineral soil or mix mineral and organic materials to provide a good seedbed (e.g., intense burns, mechanical site preparation). Regeneration of cottonwood and willow are also encouraged by mineral soil exposure (Haeussler et al. 1990). Regeneration of birch from seed can by discouraged by minimizing soil disturbance and maintaining ground cover of leaf litter (Haeussler et al. 1990; Peterson et al. 1997). Birch that originates from seed has relatively slow initial growth rates (10–20 cm/yr on mesic ICH sites) but reaches a height of about 4 m by age 10 years (Simard and Vyse 1992). Birch can reproduce abundantly from seed; depending on seedbed characteristics, densities can range from 1000 to 10 000 stems/ha following moderately intense bunch-and-burn treatments to 10 000–30 000 stems/ha following severe site preparation treatments that expose mineral soil (Simard and Vyse 1992, 1994). However, birch is very shade-intolerant and self-thins rapidly. Ingress is minimal more than 2–3 years after site disturbance (Peterson et al. 1997). In the ICH zone, birch densities are typically reduced to 5000–10 000 stems/ha at age 10 years, about 1500 stems/ha at age 15 years, and 500 stems/ha at age 70 years (Simard and Vyse 1992, 1994).

Sprouting of cut or burned birch stems can also contribute substantially to birch density on sites where there was a high component of vigorous birch in the original stand. Cut stumps sprout from adventitious buds located just below ground level (Peterson et al. 1997). Sprouts are often produced in very large numbers, especially on mature stumps; within 1–2 years of cutting, we have observed in excess of 100 sprouts on single birch stumps. Sprout growth is vigorous because of the large store of carbohydrates in the roots. Sprouts commonly increase in height at rates of 0.5–2 m/yr on mesic to subhygric sites in the ICH zone, and may reach 7 m tall by age 10 years (Simard and Vyse 1992). Sprouting is most prolific when birch are young, under high light and temperature conditions (Johansson 1985; Peterson et al. 1997).

Interactions with Conifer Seedlings

In southern interior British Columbia, the *Mixed Broadleaf-Shrub* Complex is considered a serious long-term competitor with conifers (Kimmins and Comeau 1990). Birch dominates the community, and can attain 50–100% cover 5–10 years after disturbance (Mather 1988). In the ICH zone, its juvenile height growth in full sunlight exceeds that of all conifers except western larch (Simard and Vyse 1994). In young stands, competition between broadleaves and conifers is mainly for light, although drought stess experienced by conifers can also be exacerbated by broadleaf presence on mesic and drier sites (Simard 1990a). Burton (1996) reported that conifers growing in 8- to 12-year-old birch patches in the CWHdm experienced severe light competition. As stands age, birch competition appears to lessen, and shift away from light toward soil resources (Simard and Sachs 2001, in review). Broadleaf trees can also physically damage conifers through vegetation-press and abrasion from branches (whipping) (Lees 1966; Haeussler et al. 1990; Simard 1990a). Several studies have demonstrated that vigorous, abundant birch can reduce survival and suppress growth of pine, spruce, or Douglas-fir (Gregory 1966; Andersson 1985; Simard 1990a; Simard and Heineman 1996c; Simard and Hannam 2000). Simard (2001, in review) showed that conifer species tolerate competition with paper birch in the order of western redcedar > Douglas-fir > western larch, which follows traditional interpretations of conifer shade tolerance (Krajina et al. 1982). At low to moderate densities that are common in many ICH plantations, however, birch appears to have small effects on the growth of moderately shade tolerant conifers (Simard 2001, in review).

In spite of its competitive ability, the presence of some birch in conifer stands is beneficial to ecosystem health and productivity. For instance, paper birch foliage is high in nutrients, especially nitrogen, phosphorus, sulphur, calcium, magnesium, and potassium (Simard 1995; Wang et al. 1996), which are returned annually to the soil through leaf fall. In support of this, a modelling study showed that eliminating birch from mixed Douglas-fir–birch stands would reduce site productivity over multiple rotations (Sachs 1992). There is also a growing body of research regarding the diverse rhizosphere community associated with birch, and considerable evidence that it benefits conifers when maintained in a healthy condition. For example, nitrogen-fixing bacteria have been identified in association with birch roots (Simard 1995), and there is evidence that nutrients (in this case carbon) are transferred between birch and Douglas-fir via shared ectomycorrhizae (Simard et al. 1997a). Jones et al. (1997) found that ectomycorrhizal diversity on Douglas-fir seedling roots was greater when seedlings were grown in mixture with paper birch rather than in pure stands. Birch may also contribute to the health of conifer seedlings by reducing the spread of *Armillaria* root disease (Morrison et al. 1991), discouraging spruce weevil (*Pissodes strobi*) attack (Stiell and Berry 1985; Taylor et al. 1994), providing protection from frost damage (Andersson 1985; Stathers 1989), and reducing the incidence of ungulate browsing (Simard and Heineman 1996a). Maintaining some broadleaves in young stands also contributes to the vertical stratification and complexity that is typical of mixed ICH-zone forests (Cameron 1996).

Importance to Wildlife and Range

Paper birch, aspen, and cottonwood are all important sources of food and habitat for ungulates, small mammals, and birds in British Columbia. Thimbleberry and fireweed are also utilized by wildlife, but to a lesser degree than broadleaf trees. In this section, we focus on the importance of birch to wildlife and range, because it tends to dominate the *Mixed Broadleaf-Shrub* Complex. The importance of thimbleberry and fireweed to wildlife and range are discussed in detail in the *Mixed Shrub* and *Fireweed* complexes, respectively.

Young paper birch stands provide year-round browse and summer cover for deer and moose, and winter browse for Rocky Mountain elk, caribou, and mountain goat (Peterson et al. 1997). It takes 3–5 years following disturbance for birch to provide an adequate supply of browse, and peak browse production occurs 10–16 years after logging, fire, or other disturbance (Burns and Honkala 1990). This coincides with the time that brushing is usually done in the *Mixed Broadleaf-Shrub* Complex. Loss of birch as a result of herbicide treatment can have a significant effect on moose food supply (Peterson et al. 1997) and can cause ungulates to switch to conifers for browse (Simard and Heineman 1996a; Mather and Simard 1998n). Mature birch has essentially no browse value, but understorey plants are important food sources (Burns and Honkala 1990).

The buds, catkins, and new leaves of paper birch provide food for snowshoe hares, porcupines, beavers, squirrels, mice, and voles (Peterson et al. 1997). Snowshoe hares also feed on twigs, stems, or bark of birch, often girdling or damaging the trees. Squirrels feed on flowers and leaf buds in the spring (Haeussler et al. 1990), and voles and other rodents can consume large quantities of birch seed. Beavers sometimes use birch for dam and lodge construction, but they prefer aspen (Peterson et al. 1997). Runciman and Sullivan (1996) studied the effects of brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex on small-mammal populations, and found that they were unaffected by structural changes in the vegetation that lasted up to 2 years.

Birch, cottonwood, and aspen are very important in providing snags for cavity-nesting birds, and broadleaf trees produce snags in less time than conifers (Machmer and Steeger 1995). Many birds, including woodpeckers, owls, hawks, sapsuckers, flycatchers, and vireos, nest in stem cavities or branches (Cannings et al. 1987). The buds, young twigs, and seeds of birch are an important food for several bird species (Peterson et al. 1997).

Sheep graze birch and thimbleberry minimally or erratically, but aspen and fireweed are preferred forage (Newsome et al. 1995). Cattle have low preference for fireweed, but find it most palatable when it is flowering (McLean 1979).

Common Brushing Treatments in the *Mixed Broadleaf-Shrub* Complex

The *Mixed Broadleaf-Shrub* Complex has been extensively brushed in southern interior British Columbia. Today there are few backlog (NSR) sites dominated by this complex, and few 10- to 20-year-old mixed conifer-broadleaf stands that remain unmanipulated. Brushing treatments have historically been applied to this community in a broadcast manner because it was cheaper and easier than applying selective treatments. Recently, however, some prescriptions have called for retention of 50–500 broadleaf stems/ha, or, less commonly, up to 1000 stems/ha. Brushing in the *Mixed Broadleaf-Shrub* Complex is usually done after conifers are well established, and is frequently combined with spacing.

Manual cutting using power saws or motorized brush saws has been, and remains, the most common brushing treatment applied to the *Mixed Broadleaf-Shrub* Complex. However, in older stands where broadleaves are large (>5 cm dbh), girdling is often prescribed. It is most commonly applied where aspen and/or cottonwood form a significant portion of the community. Birch stems are difficult to girdle because they are often not round. Girdling may also be combined with manual cutting where small broadleaf stems and clumps of alder and willow are growing among larger stems. Hack and squirt is essentially the same treatment as girdling, except that herbicide is injected into the girdles. It is usually not used in the *Mixed Broadleaf-Shrub* Complex in the southern interior because girdling alone minimizes resprouting.

Glyphosate is sometimes painted on stumps immediately after cutting to control resprouting; this treatment is known as cut stump–glyphosate. A treatment with similar objectives is cut-spray glyphosate, where glyphosate is sprayed on sprouts after cut stumps have been allowed to resprout for one growing season. These treatments, while more labour-intensive than simple manual cutting treatments, can prevent resprouting broadleaves from overtopping conifers. Cut stump–glyphosate and cut-spray glyphosate are preferred over simple manual cutting in stands where conifers are relatively short at the time of brushing.

Where the *Mixed Broadleaf-Shrub* Complex is relatively short, it is sometimes treated by broadcast foliar glyphosate application. Older stands are occasionally treated by injecting glyphosate capsules into the stems. Basal application of triclopyr is also becoming popular, and has the advantage of being more selective than aerial spray treatments. In general, however, herbicide treatments have not been favoured in the *Mixed Broadleaf-Shrub* Complex because of public opposition to the use of herbicides. Details about brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex are provided in Table 107.

TABLE 107 *Common brushing treatments applied to the* Mixed Broadleaf-Shrub *Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantages
Manual cutting	1. Reduce light competition 2. Create a free-growing stand	May–October	1–2	1. Power saw 2. Motorized brush saw	$538 $538	1. Rapid resprouting of birch
Girdling	1. Reduce light competition 2. Create a free-growing stand	May–October	1	1. Chain girdler	Unknown	1. Suitable only for broadleaves >5 cm diameter 2. Birch may be difficult to girdle because it is often not round 3. Extended reductions in broadleaves may negatively affect wildlife
Cut stump–glyphosate	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Power saw and backpack sprayer or squirt bottle	Unknown	1. More expensive than manual cutting 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Cut, then spray sprouts with glyphosate	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Power saw and backpack sprayer or squirt bottle	Unknown	1. More expensive than manual cutting (requires two entries) 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Foliar glyphosate spray	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Backpack sprayer	$700	1. Suitable only for young (short) stands 2. Extended reductions in broadleaves may negatively affect wildlife 3. Difficulties obtaining herbicide permits
Basal triclopyr application	1. Reduce light competition 2. Create a free-growing stand	Unknown	1	1. Sprayer 2. Roller	Unknown	1. Extended reductions in broadleaves may negatively affect wildlife 2. Difficulties obtaining herbicide permits

[a] Based on average costs in the Kamloops and Nelson forest regions for single-entry treatments (B.C. Ministry of Forests 1999)

Manual Cutting

This section describes fifth-year conifer and vegetation responses to manual cutting of the *Mixed Broadleaf-Shrub* Complex in 5- to 8-year-old Douglas-fir plantations (n = 3) and 3- to 10-year-old lodgepole pine plantations (n = 3) in the ICH and IDF zones.

Douglas-fir in the ICH and IDF zones

Description of study sites and treatments
The response of Douglas-fir and the *Mixed Broadleaf-Shrub* Complex to manual cutting is being studied on three sites distributed throughout the Kamloops Forest Region. The sites are located at Enterprise Creek, 7 km southwest of Lillooet in the Lillooet Forest District; on the east side of Mabel Lake in the Vernon District; and at Johnson Lake, 20 km east of Barriere in the Kamloops District. The Enterprise Creek site is in the Cascade Dry Cool IDF variant (IDFdk2), the Mabel Lake site is in the Shuswap Moist Warm ICH variant (ICHmw2), and the Johnson Lake site is in the Kootenay Moist Cool ICH variant (ICHmk1).

The study areas have several similarities; all are mesic (site series 01), in mid-slope position, and of northerly aspect, and have Brunisolic sandy loam soils (Table 108). Slopes range from 10 to 45% and elevations from 450 to 1200 m. The sites were clearcut between 1979 and 1983, 10–12 years before brushing. One site was burned, one was burned and mechanically site prepared, and the third received no site preparation. Douglas-fir were planted 4–5 years after disturbance and were 5–8 years old and 80–143 cm in height at the time of brushing. About half the Douglas-fir were overtopped and most of the remainder were threatened by vegetation. Total conifer stocking ranged from 2181 to 3659 stems/ha, of which 925–1200 stems/ha were well spaced.

Birch was the dominant broadleaf on all three study sites and was increasing in height at an average rate of 40 cm/yr, compared with 15–30 cm/yr for Douglas-fir. Distribution of birch and other broadleaf trees was patchy. Birch cover and height averaged 14% and 2.9 m, respectively, while total broadleaf cover (birch, aspen, and cottonwood) averaged 16%. At each site, all broadleaves, except scattered stems, were cut near ground level. Treatments took place between July and October (details are in Table 109).

Conifer responses
Survival and vigour Five years after brushing, survival of 10- to 13-year-old Douglas-fir (5–8 years old at the time of treatment) averaged 88% in the manual cutting treatment and control (p = 0.42) (Table 110). *Armillaria ostoyae* was the major cause of conifer death in both the treatment and control, causing an average 11% mortality (2.2%/yr since brushing) (p = 0.42) (Figure 116). Other minor causes of mortality were cutting damage in the treatment (1%) and *Phellinus weirii* in the control (1%). The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (502 stem/ha) than the control (315 stems/ha) (p = 0.04).

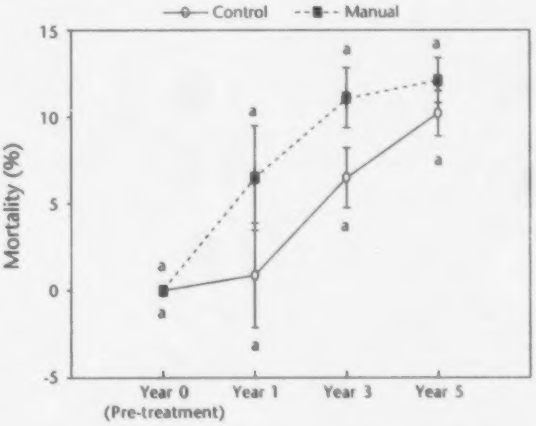

FIGURE 116 *Comparison of mean Douglas-fir mortality due to* Armillaria *between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 108 *Characteristics and history of the three replicate study sites where the ICH/IDF Mixed Broadleaf-Shrub Complex was manually cut in Douglas-fir plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Enterprise Creek PROBE 3 Lillooet District	IDFdk2 01 (mesic)	950	N 45%	Brunisol/ sandy loam	Clearcut 1979–1981	10	n/a	5	P 1985	PSB 313 1+0	5	87 (30)	Birch cover: 15 (15) Birch height: 307 (177) Soopolallie cover: 20 (16) Soopolallie height: 176 (133)	3659	925
Mabel Lake PROBE 12 Vernon District	ICHmw2 01 (mesic)	450	NW 35%	Brunisol/ sandy loam	Clearcut 1983 Burned 1983	12	12	4	P 1985	PSB 313 1+0	8	143 (29)	Birch cover: 7 (8) Birch height: 221 (98)	3095	1200
Johnson Lake PROBE 29 Kamloops District	ICHmk1 01 (mesic)	1200	NW 10%	Brunisol/ sandy loam	Clearcut 1981 Burned 1981 MSP 1983	12	10	5	P 1987	PSB 313 1+0	5	80 (24)	Birch cover: 20 (15) Birch height: 327 (91)	2181	1062

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 109 *A description of manual cutting treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH/IDF* Mixed Broadleaf-Shrub *Complex*

Site	Treatment date	Treatment type	Broadleaf retention (stems/ha)	Treatment specification
Enterprise Creek	October 1991	Broadcast	Scattered	Vegetation within 1.5 m of seedlings was cut near ground level. All woody vegetation taller than 50 cm was cut.
Mabel Lake	August 1991	Broadcast	Scattered	All broadleaves >50 cm tall and <10 cm diameter were cut near ground level.
Johnson Lake	July 1993	Broadcast	Scattered	All broadleaves were cut near ground level except where no well-spaced conifer was present. Broadleaf stems were preserved in those spots.

TABLE 110 *Survival and growth responses of Douglas-fir seedlings to manual cutting in the ICH/IDF* Mixed Broadleaf-Shrub *Complex*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	93	99	2.619	0.22
3 yr post-treatment	88	94	1.135	0.07*
5 yr post-treatment	87	89	1.311	0.42
Mortality due to Armillaria (%)				
Pre-treatment	0	0	0.000	1.00
1 yr post-treatment	7	1	3.000	0.32
3 yr post-treatment	11	7	1.734	0.20
5 yr post-treatment	12	10	1.311	0.42
Stem diameter (cm)				
Pre-treatment	1.86	2.05	0.026	0.04*
1 yr post-treatment	2.61	2.70	0.032	0.02*
3 yr post-treatment	3.87	3.58	0.034	0.42
5 yr post-treatment	5.14	4.51	0.009	0.01*
Diameter increment (cm)				
1 yr post-treatment	0.62	0.50	0.022	0.54
3 yr post-treatment	0.65	0.46	0.017	0.43
5 yr post-treatment	0.66	0.48	0.005	0.12
Height (cm)				
Pre-treatment	105.3	101.5	2.530	0.40
1 yr post-treatment	139.0	145.2	1.198	0.07*
3 yr post-treatment	200.1	201.8	5.878	0.86
5 yr post-treatment	271.9	257.6	4.622	0.16
Leader length (cm)				
Pre-treatment	24.3	23.5	0.423	0.30
1 yr post-treatment	24.4	26.7	0.464	0.08*
3 yr post-treatment	36.0	32.0	2.573	0.38
5 yr post-treatment	42.6	33.0	0.346	0.00*
Height:diameter ratio				
Pre-treatment	57.0	49.2	2.084	0.12
1 yr post-treatment	53.2	53.8	0.451	0.51
3 yr post-treatment	51.6	57.0	2.475	0.96
5 yr post-treatment	53.0	57.7	1.126	0.85

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

The vigour of Douglas-fir seedlings generally improved during the 5-year measurement period, and the improvement was somewhat greater in the brushing treatment than in the control. The percentage of good-vigour trees improved from 8 to 40% in the treatment, and from 17 to 25% in the control (Figure 117). The percentage of poor-vigour trees decreased from 16 to 8% in the treatment, and from 14 to 7% in the control.

Growth Stem diameter and leader length responded positively after brushing, but differences did not become significant ($p \leq 0.10$) (Table 110) until 5 years after treatment. There was an initial negative height response in year 1, where both leader length (Figure 118) and total height were significantly less in the brushing treatment than in the control ($p \leq 0.10$); however, these differences disappeared by year 3.

Average stem diameter was significantly less in the manual cutting treatment than in the control before treatment ($p = 0.04$), but 5 years afterward it was 14% greater in the treatment than in the control (5.14 cm versus 4.51 cm, $p = 0.01$) (Figure 119). Covariance analysis was applied to the stem diameter data in years 1 through 5. In year 5, average diameter increment was 0.18 cm greater in the manual cutting treatment than in the control (0.66 versus 0.48 cm, $p = 0.12$), and average leader length was 9.6 cm greater (42.6 cm versus 33.0 cm, $p = 0.00$). Seedling height was not affected by the treatment ($p = 0.86$ in year 3 and $p = 0.16$ in year 5). There was no difference in height:diameter ratio between the treatment and control during the 5-year measurement period.

Standardized distributions for Douglas-fir stem diameter show that, prior to treatment, there were more trees in +1 to +1.5 classes in the control than in the treatment (Figure 120). This is consistent with ANOVA, which found pre-treatment differences in stem diameter. The trend of larger diameters in the control gradually changed following manual cutting, and by year 5, the treatment distribution was skewed upward, relative to the control. This also supports ANOVA results of significantly larger stem diameters among treated control trees by year 5. The consistent nature of the

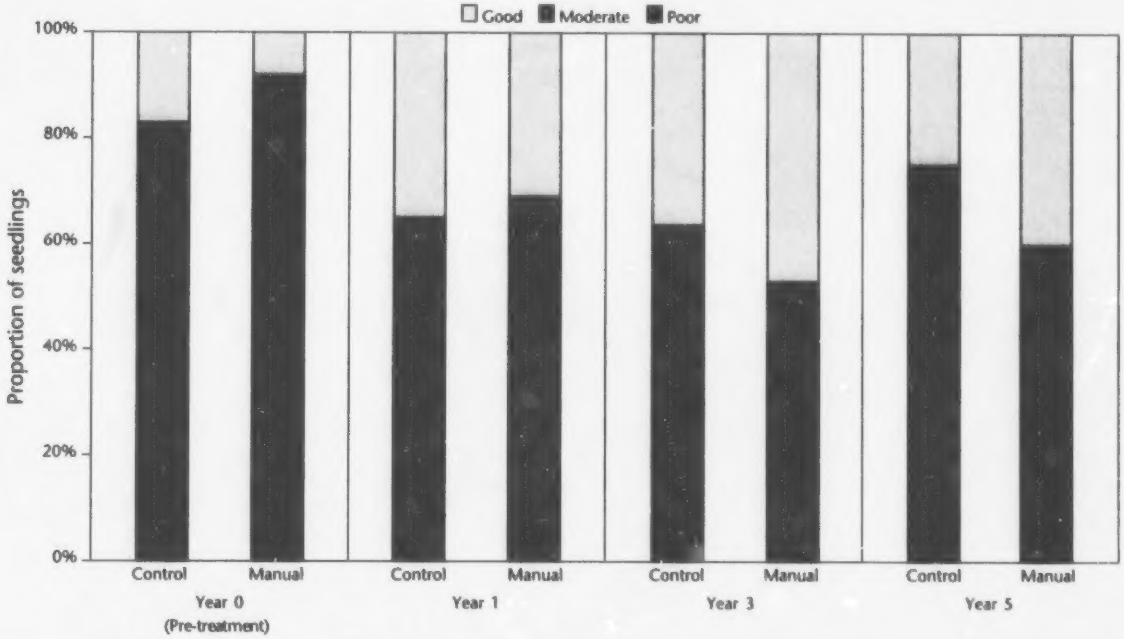

FIGURE 117 *Comparison of Douglas-fir vigour between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Good vigour seedlings had vigorous shoot growth, large leaf area, long and deep green needles, and thick caliper. Poor vigour seedlings had little or etiolated shoot growth, few and/or short needles, and small caliper. Moderate-vigour seedlings were intermediate between the good and poor classifications.*

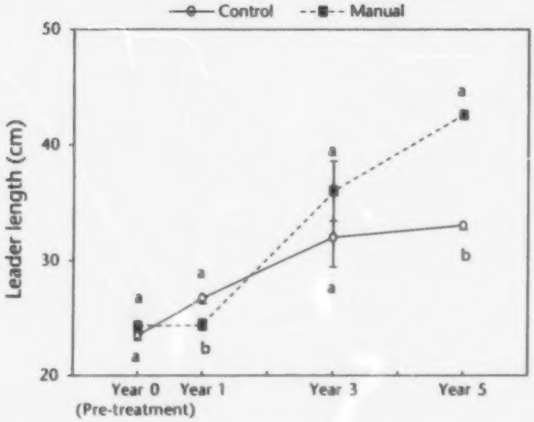

FIGURE 118 *Comparison of mean Douglas-fir leader length between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

shift of treated trees to larger diameter classes suggests that the difference will be maintained. Standardized height distributions were similar in the treatment and control prior to brushing (Figure 121), but 1 year later, the frequencies in >0 classes had increased in the control and decreased in the treatment. This suggests a negative treatment response, but by year 5, distributions were again similar in the treatment and control, and had returned to being approximately normal. Changes in the standardized height distributions are consistent with ANOVA results.

Competitive status Manual cutting considerably increased the number of conifers that were free of vegetation, decreased overtopping by birch, and increased the average height of conifers relative to neighbouring vegetation (Figure 122). One year after treatment, the percentage of conifers that were free of vegetation had increased from 2 to 41% and the percentage of overtopped trees had decreased from 57 to 14%. Five years after treatment, the proportion of Douglas-fir that were free of vegetation had increased to 48%, while 28% continued to be overtopped, mainly by rapidly growing birch

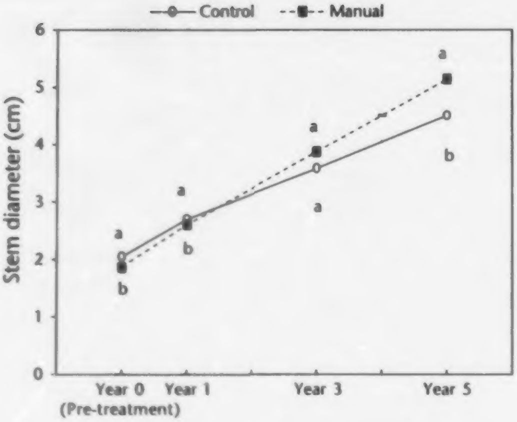

FIGURE 119 *Comparison of mean Douglas-fir stem diameter between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10). Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.*

sprouts. Meanwhile, in the control, the proportion of trees that were free of vegetation increased from 2 to 16% and the proportion overtopped increased from 45 to 63%.

Plant community responses

Abundance Birch was significantly shorter in the brushing treatment than in the control 1 year after manual cutting (106.6 versus 382.9 cm, p = 0.03) (Table 111), and it was still shorter after 5 years (383.4 versus 684.7 cm, p = 0.02) (Figure 123). Cover of birch was not significantly reduced by manual cutting in year one, but was significantly less in the treatment than in the control in years 3 (21.2 versus 17.8%, p = 0.02) and 5 (29.9 versus 25.6%, p = 0.03). Total broadleaf cover, which included aspen and cottonwood as well as birch, was significantly less in the brushing treatment (26.8%) than in the control (32.5%) 5 years after brushing (p = 0.01). In the control, untreated broadleaves grew vigorously during the 5-year monitoring period, increasing in

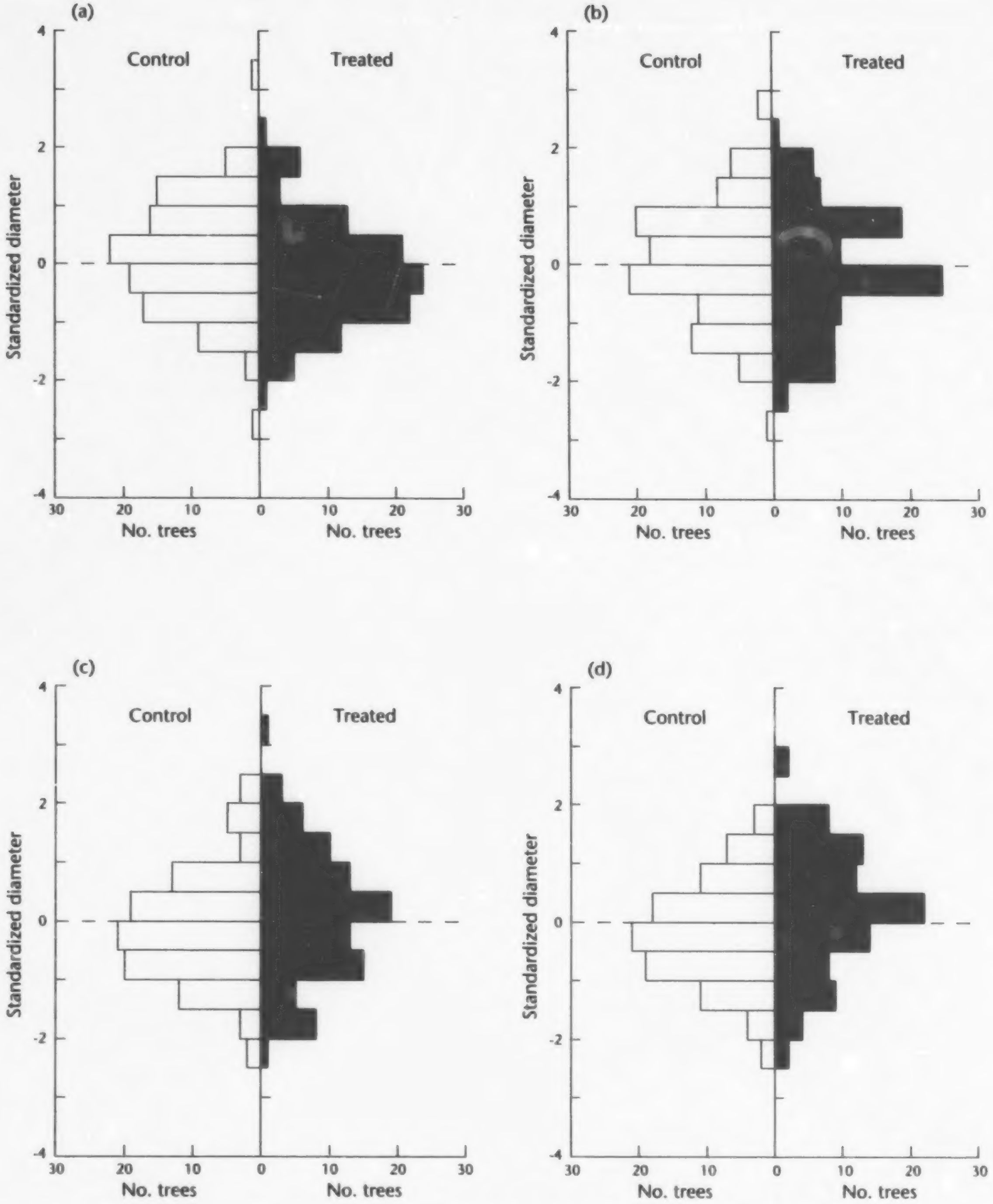

FIGURE 120 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH/IDF* Mixed Broadleaf-Shrub *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

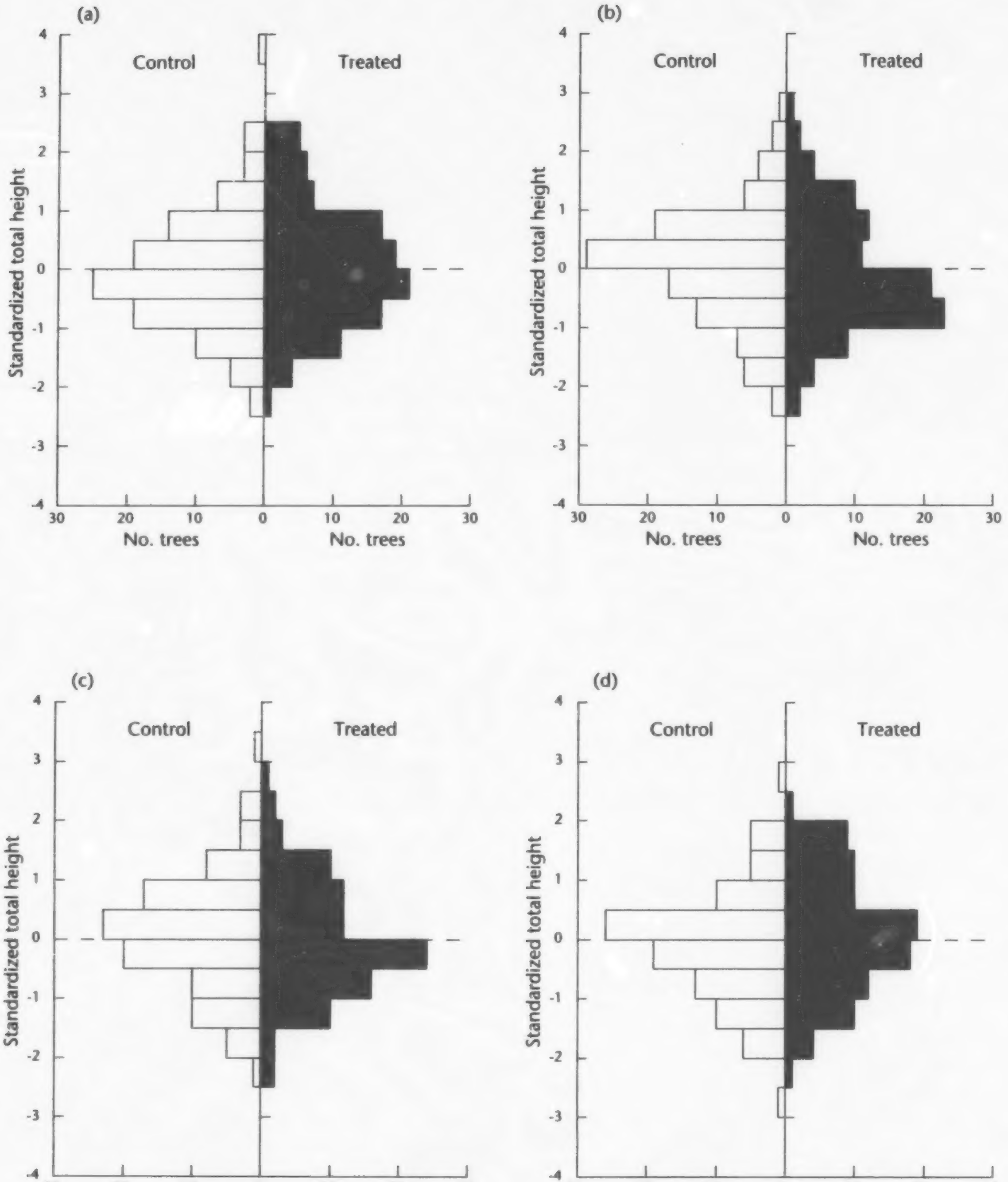

FIGURE 121 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH/IDF* Mixed Broadleaf-Shrub *Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

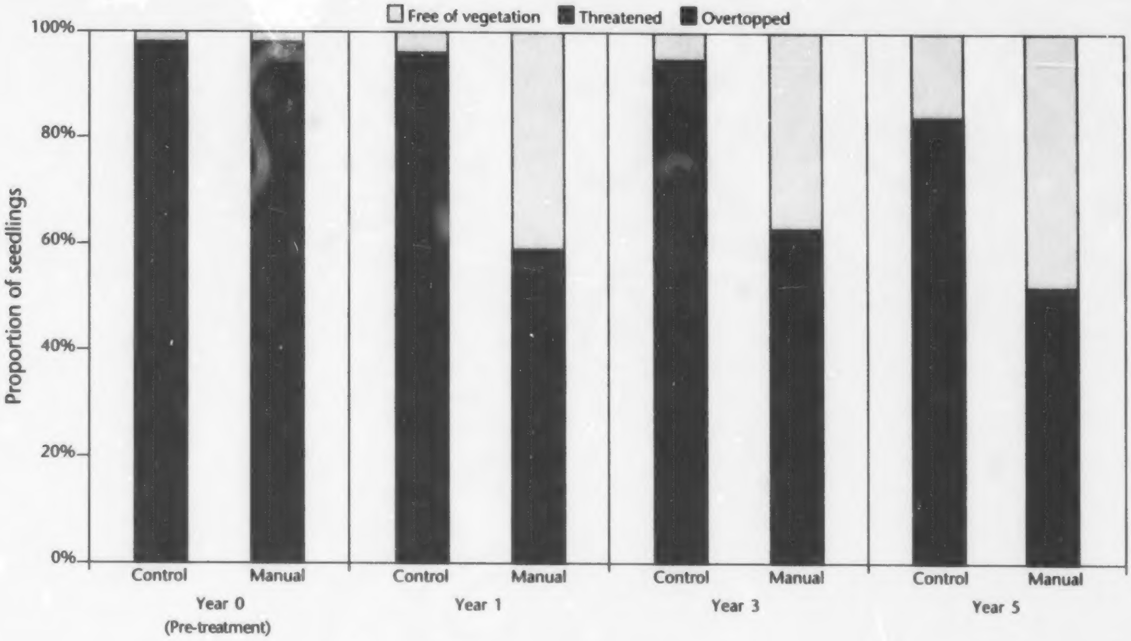

FIGURE 122 *Comparison of Douglas-fir competitive status between the manual cutting treatment and control before, and 1, 3, and 5 years after, treatment of the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

height from 283.3 to 688.3 cm and increasing in cover from 13.5 to 32.5%.

Cover and height of understorey herbs were not affected by the manual cutting treatment, and nor was cover of shrubs ($p>0.10$) (Table 111). Shrub height was less in the treatment than in the control in year 3 (72.3 versus 106.8 cm, $p = 0.09$), but the difference had disappeared by year 5.

Sprouting Birch stumps sprouted vigorously after cutting. An average 93% of stumps had sprouts 1 year after treatment and, after 5 years, 86% continued to have sprouts (Table 112). The sprouts thinned and their growth rate slowed during the 5-year monitoring period. Cut stumps averaged eight sprouts that were 96 cm tall in year 1, five sprouts that were 204 cm tall in year 3, and four sprouts that were 253 cm tall in year 5.

Richness and diversity of individual species and structural vegetation groups Manual cutting of the *Mixed Broadleaf-Shrub* Complex had no effect on either species richness or diversity ($p>0.10$) (Table 113). Species richness increased considerably between the pre-treatment assessment (27 species) and the fifth-year assessment (36 species), but the increases occurred equally in the treatment and control.

Richness of structural vegetation groups did not differ between the treatment and control on any measurement date ($p>0.10$) (Table 114). Diversity of structural groups, however, was significantly greater in the brushing treatment than in the control in year 5 ($p = 0.10$) (Table 114), probably because of reduced dominance of broadleaves.

Paper birch was the main target species, and, as expected, it decreased in cover immediately after manual cutting on all three sites. Willow cover increased within a year of manual cutting, probably because of its well-known capacity for rapid sprout growth. The cutting treatment did not affect cover of any other shrub species on more than one site.

Among herbs, one-sided wintergreen (*Orthilia secunda*) was the only species that decreased in cover following manual cutting; however, several species increased (Table 115). Fireweed increased following brushing on two of three sites, possibly in response to increased light levels. Hooker's fairy bell (*Disporum hookeri*) was not present before or 1 year after

TABLE 111 *Cover and height of vegetation in the ICH/IDF* Mixed Broadleaf-Shrub *Complex before and after manual cutting in Douglas-fir plantations*

	Means			
Response variable	**Manual cutting**	**Control**	**Standard error**	**p-value**
All vegetation				
Cover (%)				
Pre-treatment	70.6	70.9	1.851	0.94
1 yr post-treatment	48.2	56.1	2.043	0.11
3 yr post-treatment	74.1	80.2	1.673	0.13
5 yr post-treatment	84.8	87.0	0.074	0.00*
Height (cm)				
Pre-treatment	203.4	179.8	16.356	0.42
1 yr post-treatment	93.8	232.9	27.841	0.07*
3 yr post-treatment	138.2	395.0	59.994	0.09*
5 yr post-treatment	317.5	592.7	44.934	0.05*
Broadleaf trees				
Cover (%)				
Pre-treatment	18.8	13.5	1.261	0.10*
1 yr post-treatment	7.3	12.8	2.002	0.16
3 yr post-treatment	19.0	23.0	1.649	0.47
5 yr post-treatment	26.8	32.5	3.659	0.01*
Height (cm)				
Pre-treatment	299.2	283.3	4.069	0.11
1 yr post-treatment	109.0	388.0	38.493	0.04*
3 yr post-treatment	229.2	512.1	68.433	0.10*
5 yr post-treatment	386.3	688.3	25.202	0.01*
Shrubs				
Cover (%)				
Pre-treatment	35.1	34.2	1.122	0.65
1 yr post-treatment	26.7	29.2	1.939	0.46
3 yr post-treatment	39.9	39.5	1.444	0.86
5 yr post-treatment	45.1	45.9	3.228	0.87
Shrubs *(continued)*				
Height (cm)				
Pre-treatment	90.9	83.1	7.524	0.54
1 yr post-treatment	72.7	98.4	12.174	0.27
3 yr post-treatment	72.3	106.8	8.065	0.09*
5 yr post-treatment	101.7	146.4	12.331	0.12
Herbs				
Cover (%)				
Pre-treatment	20.8	24.5	3.279	0.51
1 yr post-treatment	14.5	16.5	1.423	0.43
3 yr post-treatment	22.7	22.6	1.946	0.97
5 yr post-treatment	29.3	29.5	4.149	0.98
Height (cm)				
Pre-treatment	64.6	69.8	7.468	0.67
1 yr post-treatment	72.2	78.9	12.895	0.75
3 yr post-treatment	69.2	66.3	14.614	0.90
5 yr post-treatment	57.0	47.3	5.334	0.33
Paper birch				
Cover (%)				
Pre-treatment	16.8	11.3	0.841	0.04*
1 yr post-treatment	6.1	10.9	1.917	0.16
3 yr post-treatment	17.8	21.2	1.216	0.02*
5 yr post-treatment	25.6	29.9	3.233	0.03*
Height (cm)				
Pre-treatment	289.9	279.9	2.860	0.13
1 yr post-treatment	106.6	382.9	32.434	0.03*
3 yr post-treatment	222.0	501.4	74.073	0.12
5 yr post-treatment	383.4	684.7	27.331	0.02*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

treatment on any of the sites, but small amounts (1–2% cover) were found in manually cut plots in years 3 and 5 on two sites. Strawberry (*Fragaria* spp.) and tiger lily (*Lilium columbianum*) either appeared or increased in cover following cutting. Dandelion (*Taraxacum officinale*) and thistle (*Cirsium arvense*), both common exotic weeds, appeared in two or three treated plots following brushing.

Lodgepole pine in the ICH zone

Only third- and fifth-year results are presented for this treatment cell. First-year analysis was not done because data were missing for one site.

Description of study sites and treatments

The response of lodgepole pine and the *Mixed Broadleaf–Shrub* Complex to manual cutting is being studied on three sites located throughout the Kamloops Forest Region. Two of the sites are in the Moist Warm ICH variant (ICHmw3) in the Clearwater Forest District; one near Spahats Creek, 18 km northwest of Clearwater, and the other on the Homestead Forest Service Road, 40 km east of Avola. The third site is near Amphitheatre Lake, 13 km southwest of Chase in the Kootenay Moist Cool ICH variant (ICHmk1) in the Kamloops District (Figure 124).

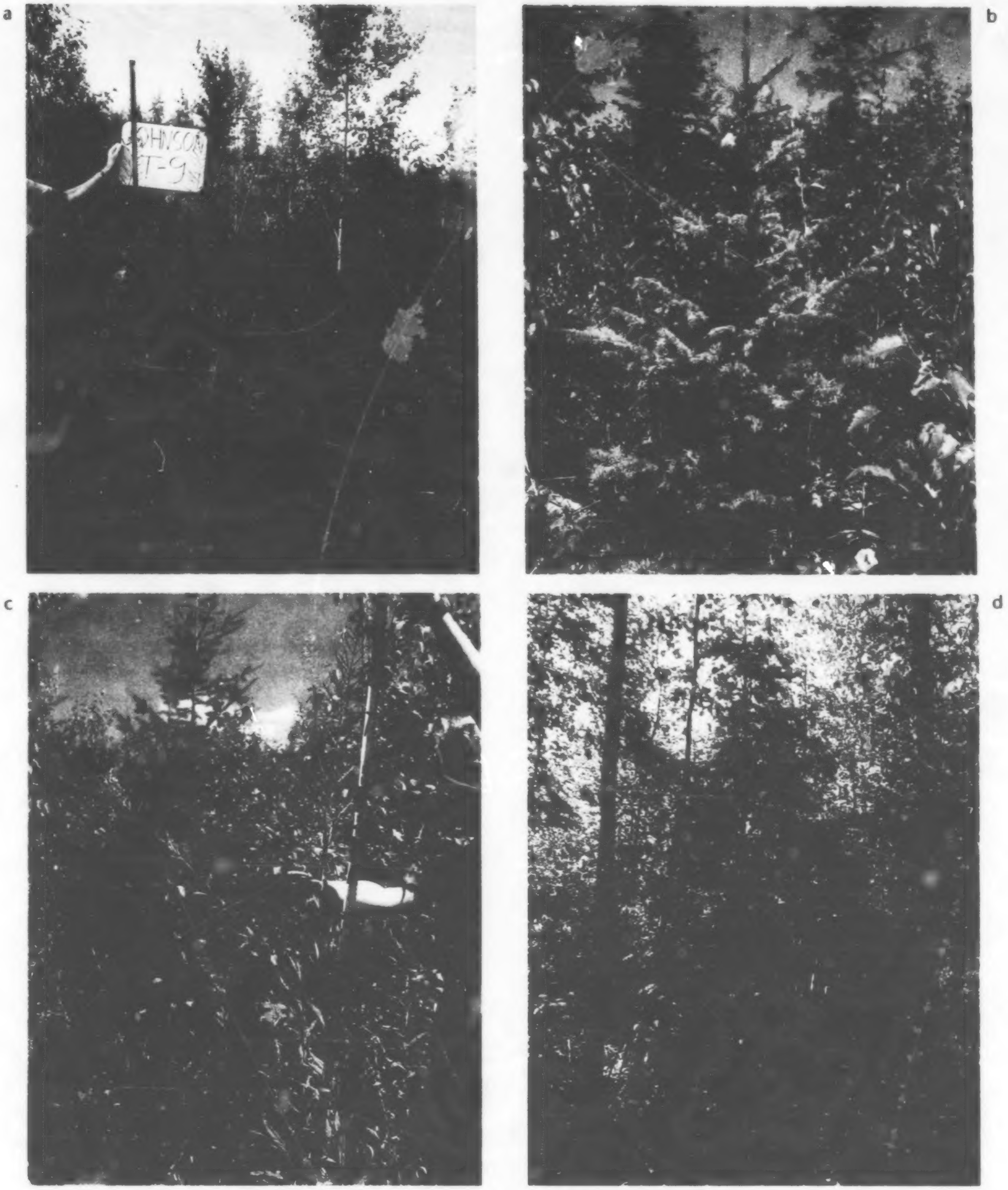

FIGURE 123 *Effects of manual cutting on the* Mixed Broadleaf-Shrub *Complex and Douglas-fir (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 3 years post-treatment for comparison. Photo credit: Jean Mather.*

TABLE 112 *Sprouting characteristics of paper birch in the ICH/IDF Mixed Broadleaf-Shrub Complex following manual cutting in Douglas-fir plantations*

Response variable	Mean
Proportion of stumps with sprouts	
1 yr post-treatment	93
3 yr post-treatment	88
5 yr post-treatment	86
Number of sprouts per stump	
1 yr post-treatment	8
3 yr post-treatment	5
5 yr post-treatment	4
Sprout length (cm)	
1 yr post-treatment	96
3 yr post-treatment	204
5 yr post-treatment	253

TABLE 113 *Richness and diversity of vascular plant species in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting in Douglas-fir plantations*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Richness				
Pre-treatment	27.67	26.67	0.408	0.23
1 yr post-treatment	29.67	31.67	1.780	0.51
3 yr post-treatment	29.67	32.67	2.944	0.55
5 yr post-treatment	36.33	36.00	2.014	0.92
Shannon-Weaver Diversity Index				
Pre-treatment	1.93	1.99	0.099	0.68
1 yr post-treatment	2.25	2.24	0.014	0.68
3 yr post-treatment	2.29	2.15	0.048	0.17
5 yr post-treatment	2.33	2.23	0.098	0.53
Simpson's Diversity Index				
Pre-treatment	0.76	0.79	0.016	0.34
1 yr post-treatment	0.84	0.84	0.006	0.57
3 yr post-treatment	0.86	0.82	0.018	0.26
5 yr post-treatment	0.86	0.83	0.017	0.35

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 114 *Richness and diversity of structural vegetation groups in the ICH/IDF Mixed Broadleaf-Shrub Complex before and after manual cutting in Douglas-fir plantations*

	Means			
Response variable	Manual cutting	Control	Standard error	p-value
Richness				
Pre-treatment	7.33	7.00	0.236	0.42
1 yr post-treatment	7.00	7.33	0.236	0.42
3 yr post-treatment	7.33	7.33	0.000	1.00
5 yr post-treatment	7.33	7.33	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.32	1.35	0.058	0.71
1 yr post-treatment	1.59	1.53	0.061	0.52
3 yr post-treatment	1.66	1.50	0.063	0.23
5 yr post-treatment	1.60	1.44	0.038	0.10*
Simpson's Diversity Index				
Pre-treatment	0.64	0.67	0.023	0.54
1 yr post-treatment	0.76	0.73	0.023	0.43
3 yr post-treatment	0.77	0.72	0.027	0.28
5 yr post-treatment	0.76	0.69	0.017	0.10*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

The Spahats Creek and Homestead sites are submesic (site series 05) and the Amphitheatre Lake site is mesic (site series 01) (Table 116). Two sites have 25–40% slopes, northerly aspects, and Brunisolic sandy loam soils, while the third site (Spahats) has a 15% slope, southwest aspect, and a Brunisolic silt loam soil. Elevations of the sites vary from 900 to 1330 m.

The original stands were clearcut between 1982 and 1986, 10–11 years before brushing. One site was burned immediately after logging, one was mechanically site prepared 1 year following logging, and the third was not prepared. Two sites were planted with lodgepole pine 3–6 years after disturbance, and on the third site the pine were of natural origin. Pine varied in age from 3 to 10 years and from 0.9 to 3.5 m in height at the time of brushing. Only about 12% of pine seedlings were free of vegetation at that time, and the remainder were overtopped or threatened by vegetation. Total conifer stocking ranged from 2778 to 4189 stems/ha, of which 1044–1200 stems/ha were well spaced.

TABLE 115 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH/IDF* Mixed Broadleaf-Shrub *Complex in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		*Betula papyrifera*	
Tall shrubs	*Salix* spp.		
Low shrubs			*Mahonia nervosa* *Pachistima myrsinites* *Rosa* spp. *Rubus parviflorus* *Symphoricarpos albus*
Herbs	*Cirsium arvense* *Disporum hookeri* *Epilobium angustifolium* *Fragaria* spp. *Lilium columbianum* *Taraxacum officinale*	*Orthilia secunda*	*Chimaphila umbellata* *Galium borealis* *Goodyera oblongifolia* *Hieracium albiflorum* *Osmorhiza chilensis*

Vigorous birch dominated non-coniferous vegetation before treatment, with average cover of 13% and average height of 2.6 m. Birch were increasing in height at about 35 cm/yr, and averaged one to two times the height of pine, which were increasing in height at rates of 30–50 cm/yr. Cutting treatments on the three sites were carried out between mid-August and September, and all broadleaf trees, except scattered stems, were cut near ground level. Treatment details are provided in Table 117.

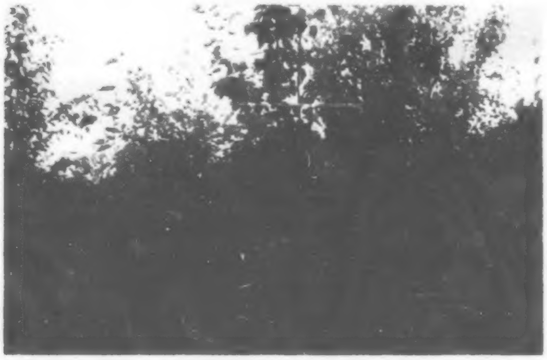

FIGURE 124 *The* Mixed Broadleaf-Shrub *Complex and lodgepole pine prior to manual cutting at Amphitheatre Lake (Site 32) in the ICHmk1 variant in the Kamloops Forest District. Photo credit: Jean Mather*

Conifer responses

Survival and vigour Survival averaged 91% in the manual cutting treatment and control 5 years after brushing (p = 0.83) (Table 118). *Armillaria ostoyae* caused significantly more mortality in the treatment than in the control in year 3 (7 versus 2%, p = 0.07) (Figure 125) and the difference tended to increase by year 5 (9% in the treatment versus 2% in the control, p = 0.16). However, variability between sites also increased, and the difference became statistically insignificant in year 5. *Armillaria* was the sole agent of lodgepole pine mortality in the treatment, whereas deer, competing vegetation, and weevils also caused mortality in the control. Five years after manual cutting, *Armillaria* had caused pine mortality at average rates of 1.8%/yr in the treatment and 0.4%/yr in the control. The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (820 stems/ha) than the control (160 stems/ha) (p = 0.02).

Average lodgepole pine vigour improved slightly in the manual cutting treatment from before treatment to 5 years afterward, and it declined in the control (Figure 126). The percentage of poor-vigour trees remained constant (2–4%) in the treatment, and increased from 12 to 23% in the control. The

TABLE 116 *Characteristics and history of the three replicate study sites where the ICH* Mixed Broadleaf-Shrub *Complex was manually cut in lodgepole pine stands*

	Site characteristics and history								Characteristics of target conifers at PROBE initiation					Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
Amphitheatre Lake PROBE 32 Kamloops District	ICHmk1 01 (mesic)	1200	NE 25%	Brunisol/ sandy loam	Clearcut 1983 Burned 1983	10	10	7	P 1984 P 1989	PSB 211 1+0	3	94 (34)	Birch cover: 17 (13) Birch height: 251 (82)	3567	1200
Homestead FSR PROBE 41 Clearwater District	ICHmw3 05 (submesic)	900	N 40%	Brunisol/ sandy loam	Clearcut 1982	11	n/a	n/a	N	n/a	10	352 (64)	Birch cover: 20 (14) Birch height: 467 (232)	4189	1044
Spahats PROBE 51 Clearwater District	ICHmw3 05 (submesic)	1330	SW 15%	Brunisol/ silt loam	Clearcut 1986 MSP 1987	10	10	3	P 1987	PSB 211 1+0	7	145 (19)	Birch cover: 3 (4) Birch height: 74 (75) Aspen cover: 5 (7) Aspen height: 120 (107) Alder cover: 10 (15) Alder height: 92 (93) Willow cover: 9 (11) Willow height: 127 (84)	2778	1200

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 117 *A description of manual cutting treatments applied to the three replicate study sites to release lodgepole pine seedlings growing in the ICH* Mixed Broadleaf-Shrub *Complex*

Site	Treatment date	Treatment type	Broadleaf retention (stems/ha)	Cutting specifications
Amphitheatre Lake	Mid-August 1993	Broadcast	Scattered	Broadleaf trees cut near ground level
Homestead FSR	September 1993	Broadcast	Scattered	Broadleaf trees cut near ground level
Spahats Creek	September 1994	1-m radius around seedlings	Scattered	All vegetation cut near ground level

percentage of good-vigour trees increased from 47 to 56% in the treatment, and declined from 43 to 6% in the control.

Growth Average stem diameter, diameter increment, and height:diameter ratio of lodgepole pine responded positively to manual cutting within 3 years, and the differences continued to be significant in year 5 ($p<0.10$) (Table 118). The average height of pine seedlings increased from 196.8 to 449.6 cm during the 5-year measurement period, but there were no differences between the treatment and control, and neither were there significant differences in leader length ($p>0.10$). Five years after brushing, average stem diameter was 37% greater in the manual cutting treatment than in the control (8.42 versus 6.14 cm, $p = 0.04$) (Figure 127). Average diameter increment was 66% greater in the treatment than in the control (1.11 versus 0.67 cm, $p = 0.04$). Prior to brushing, height:diameter ratio for pine seedlings averaged 63.1. Five years later it had increased in the control (68.5) and decreased

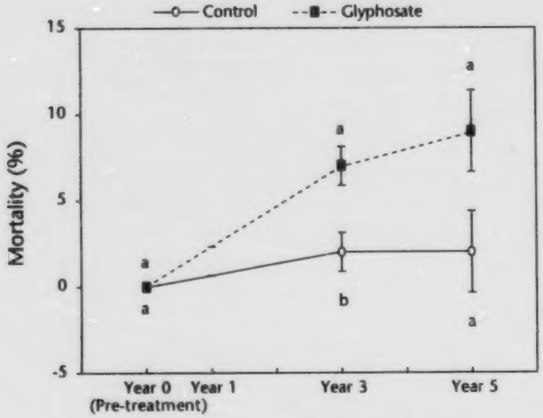

FIGURE 125 *Comparison of mean lodgepole pine mortality due to* Armillaria *between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

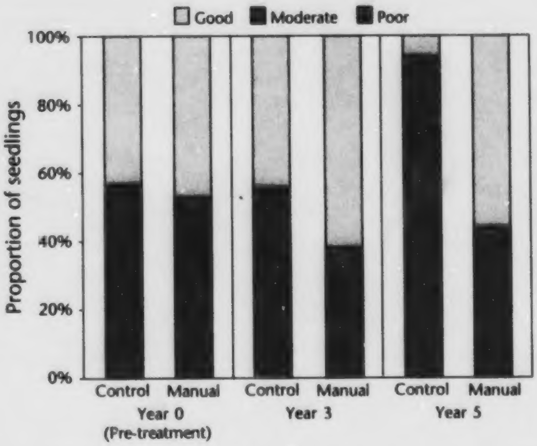

FIGURE 126 *Comparison of lodgepole pine vigour between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex.*

TABLE 118 *Survival and growth responses of lodgepole pine seedlings to manual cutting in the ICH* Mixed Broadleaf-Shrub *Complex*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Survival (%)				
Pre-treatment	100	100	0.000	1.00
3 yr post-treatment	93	95	1.140	0.25
5 yr post-treatment	91	90	1.454	0.83
Mortality due to Armillaria (%)				
3 yr post-treatment	7	2	1.133	0.07*
5 yr post-treatment	9	2	2.363	0.16
Stem diameter (cm)				
Pre-treatment	3.18	2.96	0.071	0.16
3 yr post-treatment	6.25	4.80	0.226	0.05*
5 yr post-treatment	8.42	6.14	0.333	0.04*
Diameter increment (cm)				
3 yr post-treatment	1.01	0.64	0.045	0.03*
5 yr post-treatment	1.11	0.67	0.063	0.04*
Height (cm)				
Pre-treatment	205.8	187.7	11.008	0.36
3 yr post-treatment	355.8	333.1	17.312	0.45
5 yr post-treatment	476.7	422.5	28.369	0.31
Leader length (cm)				
Pre-treatment	39.8	36.2	1.686	0.27
3 yr post-treatment	42.9	41.6	5.343	0.88
5 yr post-treatment	52.7	39.2	6.928	0.30
Height:diameter ratio				
Pre-treatment	62.6	63.6	2.159	0.78
3 yr post-treatment	55.1	68.2	1.132	0.01*
5 yr post-treatment	56.0	68.5	0.309	0.00*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

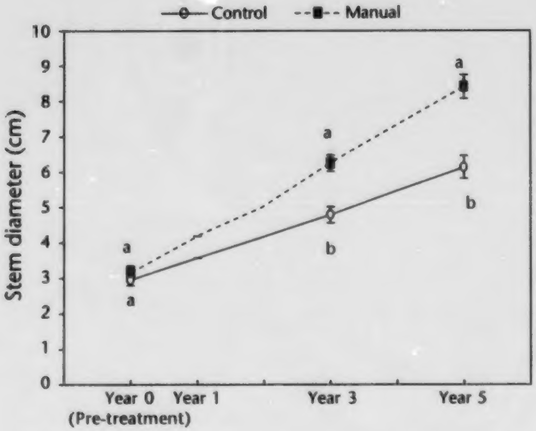

FIGURE 127 *Comparison of mean lodgepole pine stem diameter between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

in the treatment (56.0) (p = 0.00) (Figure 128), indicating that treated trees had become sturdier and control trees more spindly.

Standardized diameter distributions show an increase in the frequency of treated pine in larger classes relative to the control (Figure 129). This trend became pronounced in year 3 and continued into year 5, and is consistent with ANOVA results that pine stem diameter became significantly larger in the treatment than in the control following manual cutting. The nature of the trend suggests that most pine are responding to the cutting treatment. ANOVA showed no significant differences in pine height between the treatment and the control, but the standardized height distributions suggest that treated trees are beginning to increase in height relative to the control. Heights were distributed approximately normally prior to treatment, and the distributions were similar in the treatment and the control (Figure 130). By year 5 the frequency of treated trees had increased in larger height classes, while control trees continued to be normally distributed.

Competitive status Manual cutting immediately eliminated overtopping, resulting in a large increase in the number of pine that were free of vegetation (Figure 131). Untreated seedlings were slowly outgrowing the vegetation, but only a modest proportion (36%) were free of vegetation or threatened at the end of the 5-year measurement period. In the manual cutting treatment, the percentage of pine that were free of vegetation or threatened increased from 3 to 79%, and the percentage overtopped

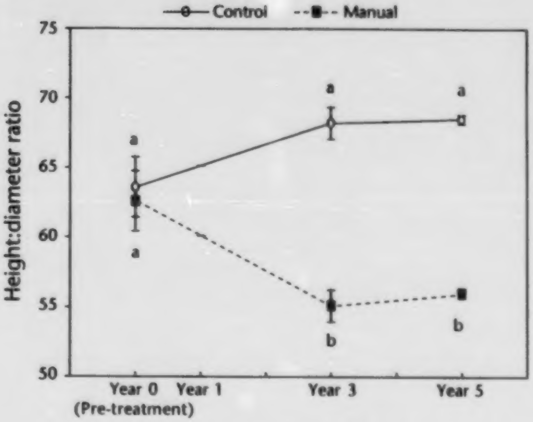

FIGURE 128 *Comparison of mean lodgepole pine height:diameter ratio between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean* ($\bar{y}$) *which was calculated as* $S_{\bar{y}} = \sqrt{MSE/n}$ *where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance* ($\propto = 0.10$).

decreased from 56 to 21%. In comparison, the percentage of control trees that were overtopped increased from 46 to 67%.

Plant community response

Abundance Birch height, but not cover, was significantly reduced for 5 years following manual cutting (Figure 132). Five years after treatment, birch had recovered in height to 229.8 cm in the treatment, but was still much shorter than birch in the control (485.5 cm, p = 0.03) (Table 119). Average birch cover was substantially lower in the brushing treatment than in the control 5 years after treatment (19.7 versus 34.4%), but due to high variability, the difference was not significant (p = 0.23).

Herb cover and height were not affected by manual cutting, and neither was shrub cover (p>0.10) (Table 119). Shrub height was significantly less in the manual cutting treatment than in the control in year 3 (65.8 versus 115.6 cm, p = 0.06), but the difference disappeared by year 5.

Sprouting Birch sprouted vigorously after manual cutting, but the abundance of sprouts decreased with time and their average height did not increase. Three years after treatment, 81% of cut stumps had sprouts, and the proportion decreased to 67% within 5 years. Cut stumps averaged eight sprouts that were 207 cm tall in year 3 and five sprouts that were 200 cm tall in year 5 (Table 120).

Richness and diversity of individual species and structural vegetation groups Manual cutting of the *Mixed Broadleaf-Shrub* Complex had no effect on richness or diversity of vascular plant species or structural vegetation groups (p>0.10) (Tables 121 and 122). As expected, paper birch, the primary target species, decreased in abundance following manual cutting. Many herb and shrub species increased or decreased in the treated plots of these study sites, but there were no obvious trends across more than one site (Table 123).

Cut Stump–Glyphosate

Douglas-fir in the ICH zone

This section describes fifth-year Douglas-fir and vegetation responses to cut stump–glyphosate treatment of the *Mixed Broadleaf-Shrub* Complex in the ICH zone (n = 3) (Figure 133). Conifers were 8–9 years old at the time of treatment.

Description of study sites and treatments

The response of Douglas-fir and the *Mixed Broadleaf-Shrub* Complex to cut stump–glyphosate treatment is being studied on three sites in the Kamloops Forest Region. Two are located near East Barriere Lake, 27–30 km northeast of Barriere in the Kamloops District: one in the Kootenay Moist Cool ICH variant (ICHmk1) and one in the Thompson Moist Warm ICH variant (ICHmw3). The third site is at Larch Hills, 15 km southwest of Sicamous in the Salmon Arm District, in the Shuswap Moist Warm ICH variant (ICHmw2).

The study areas have similar site characteristics; all are mesic (site series 01), in mid-slope position, of generally northerly aspect, on 25–30% slopes, and have Brunisolic sandy loam soils (Table 124). Elevations range from 870 to 1070 m.

The three sites were clearcut between 1976 and 1982. The two sites in the Kamloops District were mechanically site prepared and the site at Larch Hills was broadcast burned. Site preparation took place 1–2 years after logging and 8–13 years before

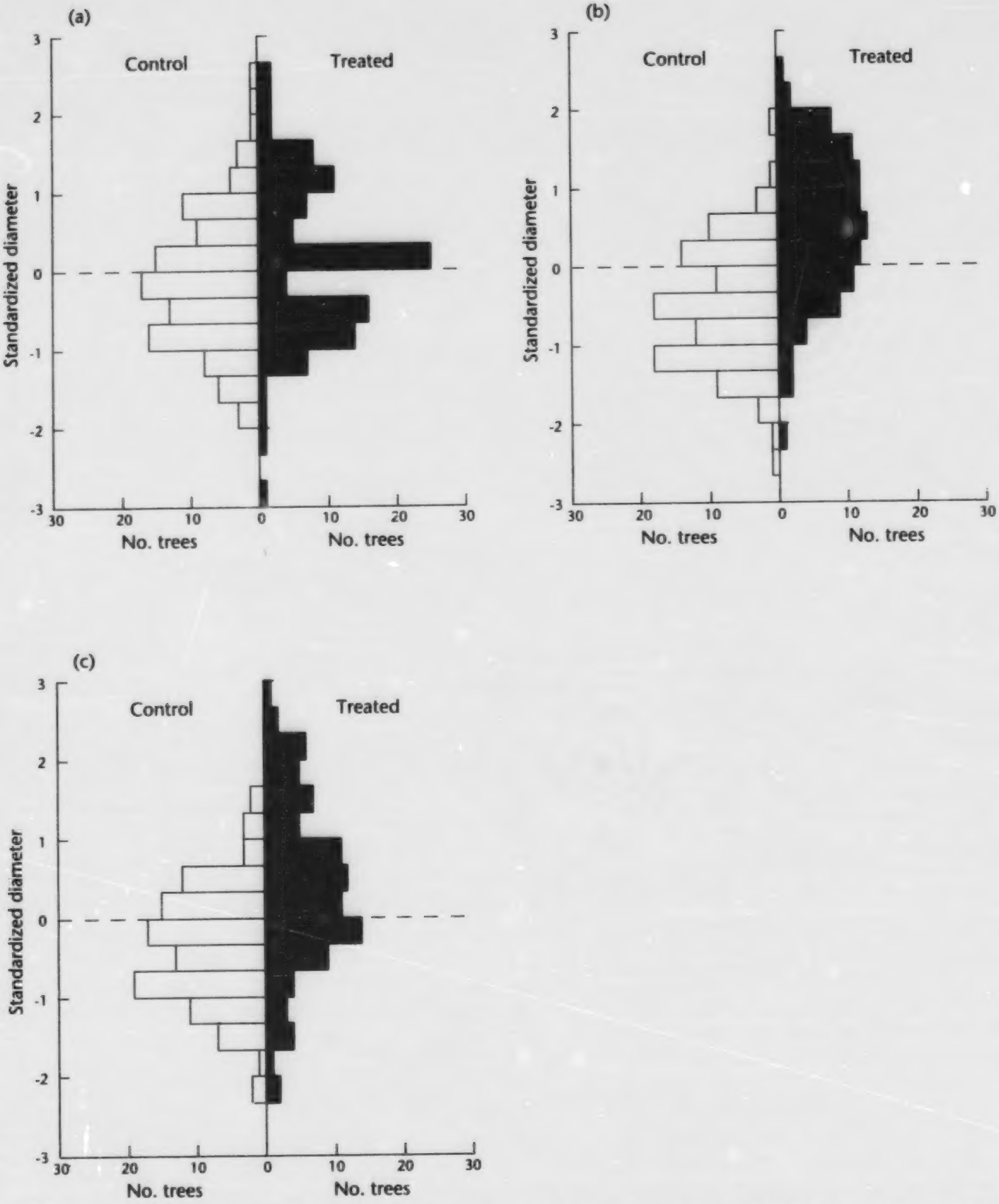

FIGURE 129 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the ICH* Mixed Broadleaf-Shrub Complex *before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 3 years post-treatment; (c) 5 years post-treatment.*

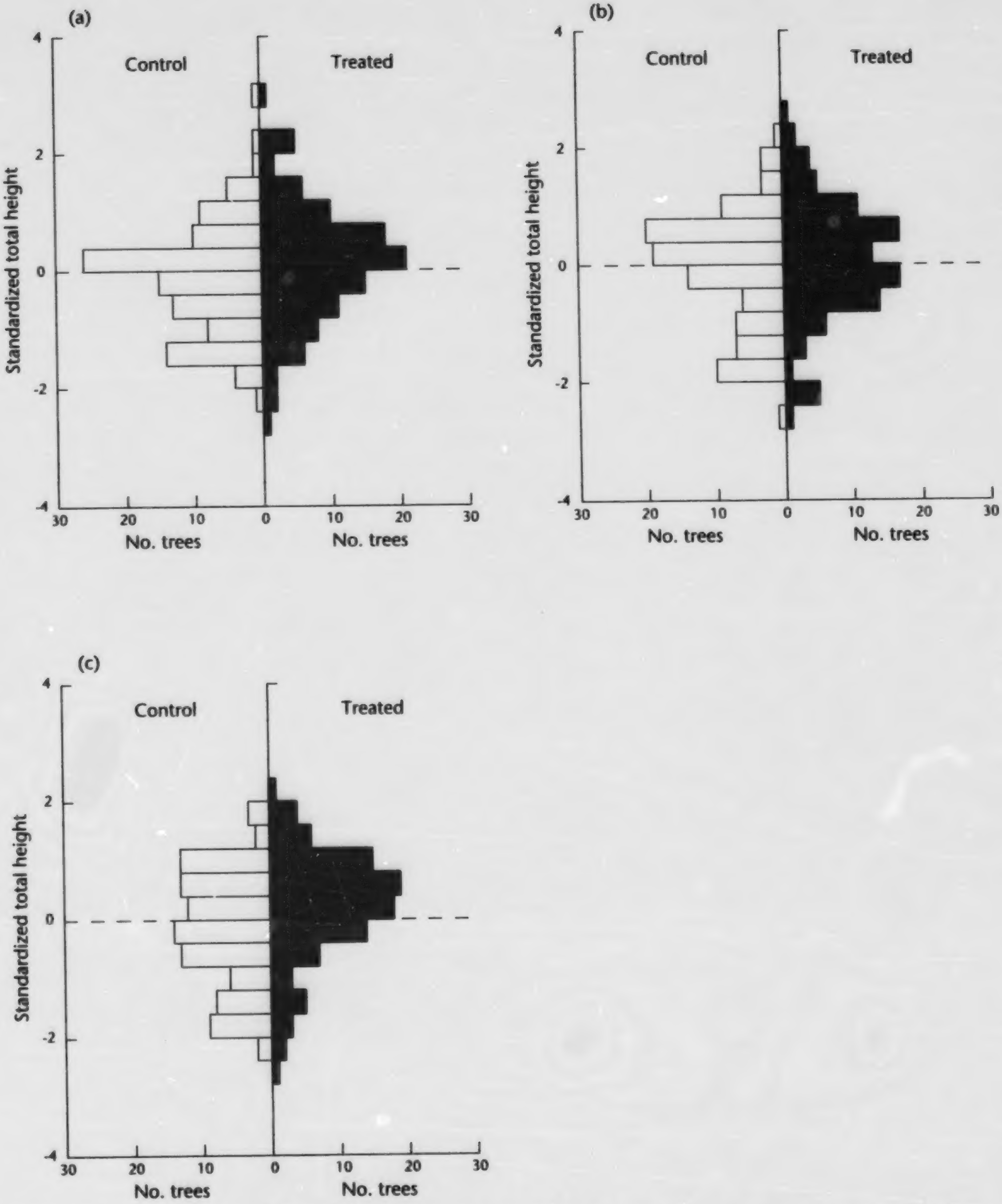

FIGURE 130 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for lodgepole pine in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting. Graphs are for: (a) pre-treatment; (b) 3 years post-treatment; (c) 5 years post-treatment.*

TABLE 119 *Cover and height of vegetation in the ICH* Mixed Broadleaf-Shrub *Complex before and after manual cutting in lodgepole pine plantations*

	Means			
Response variable	**Manual cutting**	**Control**	**Standard error**	**p-value**
All vegetation				
Cover (%)				
Pre-treatment	68.7	75.0	2.483	0.21
3 yr post-treatment	81.8	85.8	1.692	0.24
5 yr post-treatment	89.2	94.9	4.039	0.43
Height (cm)				
Pre-treatment	207.9	221.9	13.678	0.54
3 yr post-treatment	147.1	437.7	83.379	0.13
5 yr post-treatment	329.3	504.4	48.667	0.13
Broadleaf trees				
Cover (%)				
Pre-treatment	14.3	18.2	2.515	0.39
3 yr post-treatment	15.1	35.2	7.150	0.19
5 yr post-treatment	21.0	38.9	5.477	0.15
Height (cm)				
Pre-treatment	287.7	299.1	16.725	0.68
3 yr post-treatment	176.0	554.7	38.273	0.02*
5 yr post-treatment	230.1	550.3	24.572	0.01*
Shrubs				
Cover (%)				
Pre-treatment	39.5	41.2	2.015	0.62
3 yr post-treatment	44.1	45.6	3.145	0.76
5 yr post-treatment	46.7	46.8	1.616	0.97
Shrubs *(continued)*				
Height (cm)				
Pre-treatment	91.2	99.1	6.387	0.47
3 yr post-treatment	65.8	115.6	9.014	0.06*
5 yr post-treatment	113.6	156.4	21.316	0.29
Herbs				
Cover (%)				
Pre-treatment	27.4	25.0	3.361	0.66
3 yr post-treatment	45.4	48.1	7.232	0.82
5 yr post-treatment	54.3	49.3	7.562	0.69
Height (cm)				
Pre-treatment	59.6	67.6	5.486	0.41
3 yr post-treatment	65.8	61.4	5.951	0.65
5 yr post-treatment	62.8	62.4	6.487	0.97
Paper birch				
Cover (%)				
Pre-treatment	12.0	15.1	2.668	0.50
3 yr post-treatment	13.9	30.3	7.999	0.28
5 yr post-treatment	19.7	34.4	6.072	0.23
Height (cm)				
Pre-treatment	271.0	256.9	26.574	0.74
3 yr post-treatment	170.9	495.3	58.730	0.06*
5 yr post-treatment	229.8	485.5	29.849	0.03*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

brushing. Douglas-fir were planted 1–2 years after site preparation and were 8–9 years old and 1.0–2.3 m tall at the time of brushing. About 60% of the Douglas-fir were overtopped and few were free of vegetation. Trees averaged half the height of neighbouring vegetation.

Birch was the dominant deciduous species on the sites before cut stump–glyphosate application. Its abundance varied among the sites, but cover averaged 50% (range of 40–56%) and height averaged 4.3 m (range of 2.7–5.9 m). Birch density varied from 3100 to 7800 stems/ha and most stems were vigorous. At the time of treatment, annual height growth of birch averaged 30–70 cm/yr, compared with 25–35 cm/yr for Douglas-fir. Total conifer density on these sites was 3159–7045 stems/ha, of which 1095–1200 stems/ha were well spaced.

At each site, broadleaf trees were cut near ground level and glyphosate was painted on the stumps at a rate of 0.74–3.20 kg ai/ha (Table 125). Work quality was good at two sites, but many stumps were missed during glyphosate application at the third site (John Creek). Treatments were applied between mid-June and mid-October.

Conifer responses

Survival and vigour Survival of Douglas-fir averaged 95% in the cut stump–glyphosate treatment and control 5 years after brushing (p = 0.23) (Table 126). *Armillaria ostoyae* caused almost all the mortality, but affected the treatment and control

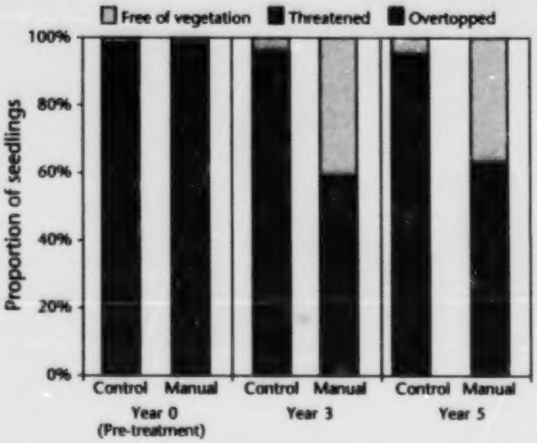

FIGURE 131 *Comparison of lodgepole pine competitive status between the manual cutting treatment and control before, and 3 and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

TABLE 120 *Sprouting characteristics of paper birch in the ICH Mixed Broadleaf-Shrub Complex following manual cutting in lodgepole pine stands*

Response variable	Mean
Proportion of stumps with sprouts	
3 yr post-treatment	81
5 yr post-treatment	67
Number of sprouts per stump	
3 yr post-treatment	8
5 yr post-treatment	5
Sprout length (cm)	
3 yr post-treatment	207
5 yr post-treatment	200

TABLE 121 *Richness and diversity of vascular plant species in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting in lodgepole pine stands*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	35.67	36.67	4.320	0.89
3 yr post-treatment	35.00	35.50	1.061	0.80
5 yr post-treatment	38.00	39.00	2.273	0.79
Shannon-Weaver Diversity Index				
Pre-treatment	2.42	2.34	0.093	0.58
3 yr post-treatment	2.33	2.22	0.162	0.71
5 yr post-treatment	2.42	2.48	0.057	0.59
Simpson's Diversity Index				
Pre-treatment	0.86	0.83	0.023	0.42
3 yr post-treatment	0.86	0.81	0.045	0.58
5 yr post-treatment	0.85	0.87	0.026	0.57

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

TABLE 122 *Richness and diversity of structural vegetation groups in the ICH Mixed Broadleaf-Shrub Complex before and after manual cutting in lodgepole pine stands*

Response variable	Means		Standard error	p-value
	Manual cutting	Control		
Richness				
Pre-treatment	7.00	7.00	0.000	1.00
3 yr post-treatment	7.00	7.50	0.354	0.50
5 yr post-treatment	7.00	7.00	0.000	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.54	1.57	0.088	0.86
3 yr post-treatment	1.65	1.59	0.124	0.81
5 yr post-treatment	1.62	1.64	0.069	0.90
Simpson's Diversity Index				
Pre-treatment	0.74	0.73	0.033	0.83
3 yr post-treatment	0.78	0.74	0.044	0.70
5 yr post-treatment	0.76	0.77	0.029	0.72

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

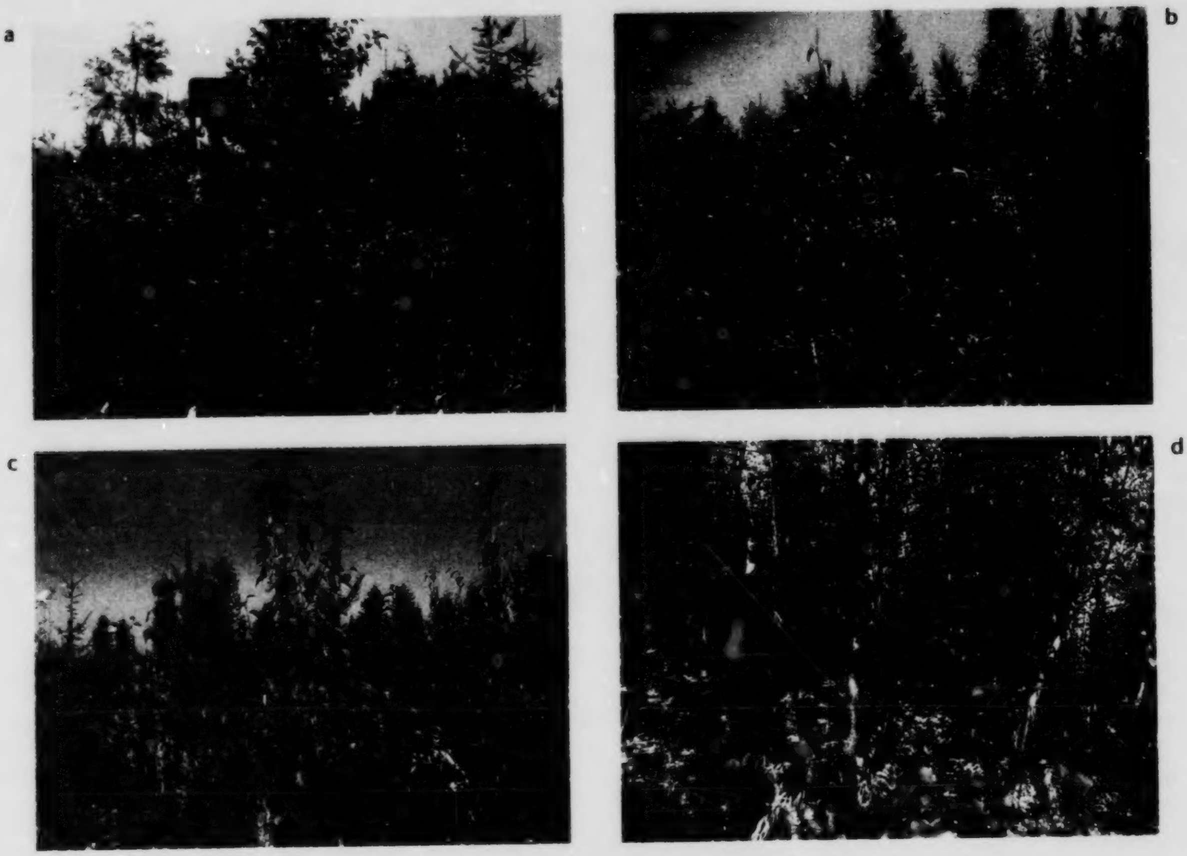

FIGURE 132 *Effects of manual cutting on the* Mixed Broadleaf-Shrub *Complex and lodgepole pine (a) 1 year, (b) 3 years, and (c) 5 years following treatment. The control (d) is shown 5 years post-treatment for comparison. Photo credit: Jean Mather.*

TABLE 123 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following manual cutting of the ICH* Mixed Broadleaf-Shrub *Complex in lodgepole pine plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		*Betula papyrifera*	
Low shrubs			*Lonicera involucrata* *Ribes lacustre* *Rubus parviflorus*
Herbs			*Chimaphila umbellata* *Lilium columbianum* *Linnaea borealis* *Smilacina racemosa*

TABLE 124 *Characteristics and history of the three replicate study sites where a cut stump–glyphosate treatment was applied to the ICH Mixed Broadleaf-Shrub Complex in Douglas-fir plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation						Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)	Total	Well spaced
John Creek PROBE 1 Kamloops District	ICHmk1 01 (mesic)	870	NE 25%	Brunisol/ sandy loam	Clearcut 1982 Piled and burned 1983	9	8	0	P 1984	PSB 313 1+0	8	98 (39)	Birch cover: 52 (17) Birch height: 266 (64)	7045	1200
Upper John Creek PROBE 2 Kamloops District	ICHmw3 01 (mesic)	920	NW 30%	Brunisol/ sandy loam	Clearcut 1976 MSP 1978 Grass seeded 1981	15	13	4	P 1979	2+1 BR	9	218 (67)	Birch cover: 40 (28) Birch height: 589 (184)	3159	1095
Larch Hills PROBE 7 Salmon Arm District	ICHmw2 01 (mesic)	1070	NW 25%	Brunisol/ silt loam	Clearcut 1980 Burned 1981–1982	11	9	1	P 1984	2+0 BR	8	228 (68)	Birch cover: 56 (15) Birch height: 447 (102)	4775	1200

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

FIGURE 133 *The Mixed Broadleaf-Shrub Complex prior to cut stump–glyphosate treatment at Upper John Creek (Site 2) in the ICHmw3 variant in the Kamloops Forest District. Photo credit: Jean Mather.*

similarly (p = 0.42) (Figure 134). The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the treatment (745 stems/ha) than the control (128 stems/ha) (p = 0.04).

Although survival was high in both the treatment and control, the average vigour of Douglas-fir declined considerably in the control while remaining constant in the brushing treatment during the 5-year measurement period (Figure 135). The proportion of poor-vigour trees increased from 11 to 39% in the control but remained constant at 6–7%

TABLE 125 *A description of cut stump–glyphosate treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH Mixed Broadleaf-Shrub Complex*

Site	Initial treatment date	Treatment type	Application rate (kg ai/ha)
John Creek	Mid-July 1991	Broadcast	0.91
Upper John Creek	Mid-June 1991	Broadcast	0.74
Larch Hills	Mid-October 1991	Broadcast; broadleaf stems >10 cm diameter retained	3.20

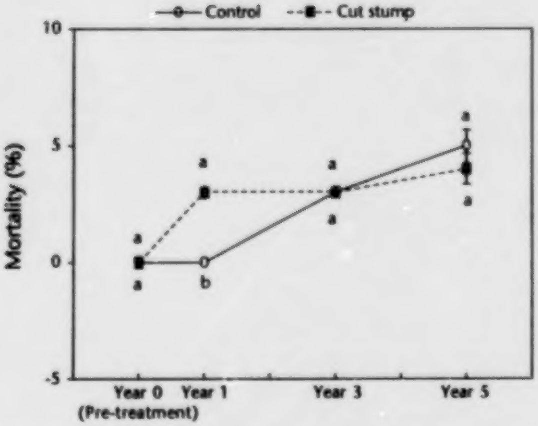

FIGURE 134 *Comparison of mean Douglas-fir mortality due to Armillaria between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH Mixed Broadleaf-Shrub Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 126 *Survival and growth responses of Douglas-fir seedlings to cut stump–glyphosate treatment in the ICH Mixed Broadleaf-Shrub Complex*

	Means			
Response variable	Cut stump–glyphosate	Control	Standard error	p-value
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	97	100	0.000	1.00
3 yr post-treatment	97	97	0.000	1.00
5 yr post-treatment	96	94	1.135	0.23
Mortality due to Armillaria (%)				
Pre-treatment	0	0	0.000	1.00
1 yr post-treatment	3	0	0.000	0.00
3 yr post-treatment	3	3	0.000	1.00
5 yr post-treatment	4	5	0.655	0.42
Stem diameter (cm)				
Pre-treatment	3.93	3.37	0.343	0.33
1 yr post-treatment	4.86	3.81	0.495	0.27
3 yr post-treatment	6.70	4.53	0.658	0.14
5 yr post-treatment	7.69	5.06	0.641	0.10*
Diameter increment (cm)				
1 yr post-treatment	1.03	0.50	0.173	0.16
3 yr post-treatment	0.92	0.37	0.093	0.05*
5 yr post-treatment	0.58	0.29	0.020	0.01*
Height (cm)				
Pre-treatment	187.7	174.8	6.636	0.30
1 yr post-treatment	237.9	220.8	16.048	0.53
3 yr post-treatment	309.9	274.7	20.831	0.35
5 yr post-treatment	398.4	318.5	17.854	0.09*
Leader length (cm)				
Pre-treatment	33.9	33.3	0.784	0.51
1 yr post-treatment	25.2	30.1	5.577	0.15
3 yr post-treatment	42.1	31.2	2.583	0.10*
5 yr post-treatment	45.3	23.0	2.773	0.03*
Height:diameter ratio				
Pre-treatment	49.3	51.4	1.978	0.61
1 yr post-treatment	50.9	58.5	2.316	0.14
3 yr post-treatment	47.4	61.5	3.352	0.10*
5 yr post-treatment	52.7	63.1	2.058	0.07*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

in the brushed treatment. In addition, the proportion of good-vigour trees decreased from 24 to 2% in the control but remained constant at 29–32% in the treated plots. Poor-vigour trees tended to be spindly with thinning foliage.

Growth Diameter increment and leader length of Douglas-fir seedlings increased in the treatment relative to the control 3 years after cut stump–glyphosate application ($p<0.10$), but significant differences in stem diameter ($p = 0.10$) (Figure 136) and height ($p = 0.09$) (Figure 137) did not appear until year 5 (Table 126). In the fifth-year assessment, average stem diameter, diameter increment, and leader length of Douglas-fir were all approximately twice as great in the treatment as in the control, and seedlings were about 25% taller. Seedlings were 13–15 years old in year 5, and were 398.4 cm tall with 7.69 cm stem diameter in the treatment, compared to 318.5 cm tall with 5.06 cm stem diameter in the control. Treated seedlings were increasing in height at approximately twice the rate of control seedlings in year 5 (leaders were 45.3 cm in the treatment versus 23.0 cm in the control). Height:diameter ratio of Douglas-fir also decreased within 3 years of the cut stump–glyphosate treatment. Before treatment, height:diameter ratio averaged 50.4 ($p = 0.61$), but 5 years later it had increased to 63.1 in the control and remained essentially unchanged (52.7) in the treatment ($p = 0.07$) (Figure 138).

Standardized diameter distributions for Douglas-fir were normal in the treatment prior to brushing, but in the control there were a comparatively large number of seedlings in the -1 to -1.5 diameter classes (Figure 139). In the control, the frequency of trees in smaller diameter classes increased further through year 5, while in the cut stump–glyphosate treatment, frequencies increased in the larger diameter classes. The difference between the control and treatment was not large enough to be statistically significant prior to treatment, but by year 5, ANOVA showed that stem diameter was larger in the treatment than in the control. The standardized height distributions were approximately normal in both the treatment and control prior to the cut stump–glyphosate treatment (Figure 140). The distribution of control heights changed very little during the 5-year measurement period, but in the treatment, frequencies increased slightly in the +1 height class. These results agree with ANOVA findings that Douglas-fir were significantly taller in the treatment than in the control by year 5. The trend of

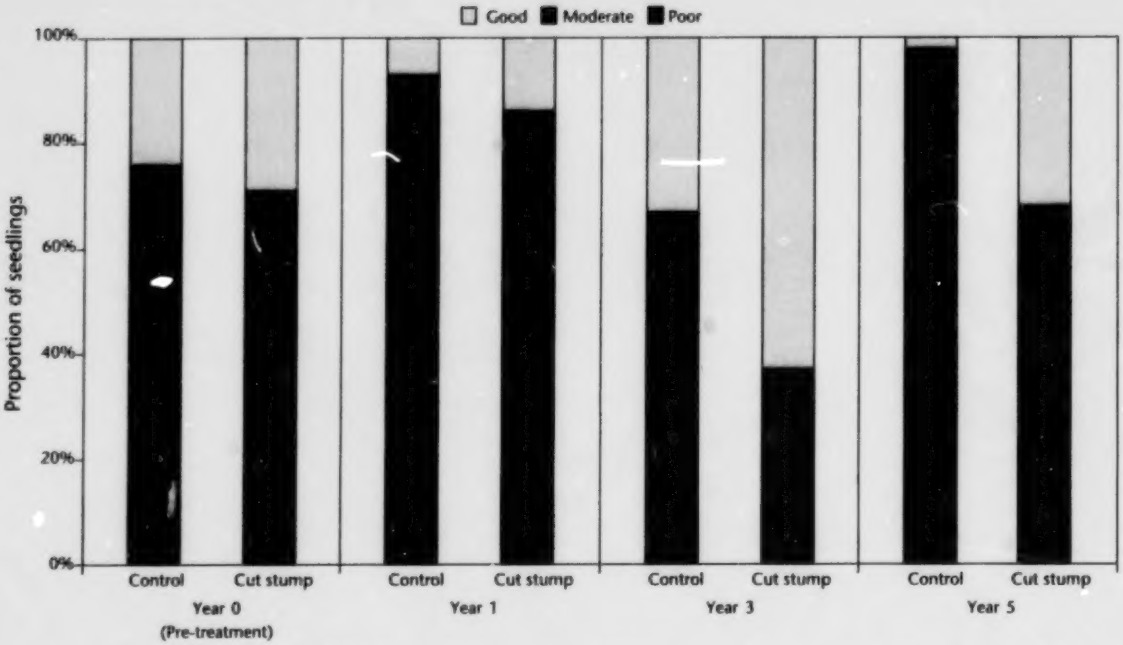

FIGURE 135 *Comparison of Douglas-fir vigour between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex.*

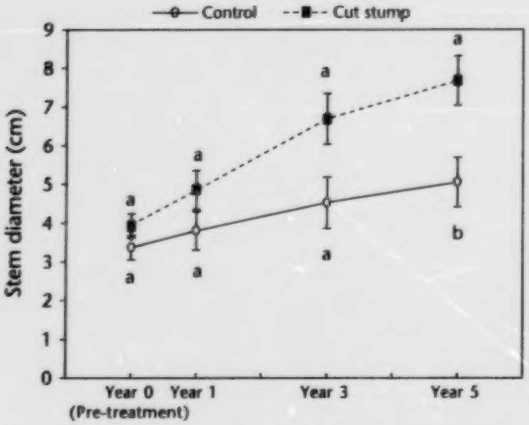

FIGURE 136 *Comparison of mean Douglas-fir stem diameter between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

increase is less pronounced for height than for diameter, and it is difficult to predict whether it will continue into future assessments.

Competitive status Cut stump–glyphosate application resulted in a large increase in the percentage of Douglas-fir that were free of vegetation and nearly eliminated overtopping (Figure 141). Within one year of treatment, the percentage of trees that were free of vegetation in the treatment increased from 3 to 63%, and the percentage overtopped decreased from 64 to 13%. These improvements remained relatively constant through year 5. Meanwhile, competitive status worsened in the control during the 5-year monitoring period; the percentage of trees free of vegetation decreased from 6 to 0%, and the percentage overtopped increased from 57 to 76%.

Plant community responses

Abundance Cut stump–glyphosate treatment reduced birch height for at least 5 years ($p<0.10$) (Table 127, Figures 142 and 143). One year after treatment, birch averaged 123.0 cm tall in the treatment compared with 543.0 cm tall in the control. By year 5, treated birch had grown about 250 cm to 376.8 cm tall, while those in the control had grown

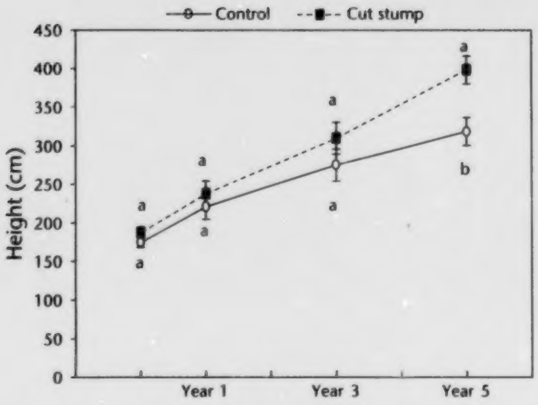

FIGURE 137 *Comparison of mean Douglas-fir height between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

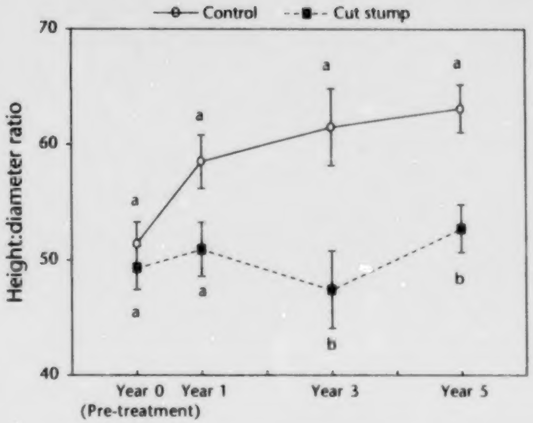

FIGURE 138 *Comparison of mean Douglas-fir height:diameter ratio between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

almost 500 cm to 932.2 cm tall. The brushing treatment also substantially reduced birch cover for at least 5 years (15.3% in the treatment compared to 64.8% in the control in year 5, p = 0.05). Birch cover in the control increased gradually from 50.1 to 64.8% during the 5-year measurement period.

Herb cover and height and shrub cover were unaffected by cut stump–glyphosate treatment of broadleaf trees. Shrub height was significantly less in the treatment than in the control 1 and 3 years after brushing (p = 0.04).

Sprouting Twenty-eight percent of birch stumps had sprouts 1 year after treatment and the proportion was about the same (24%) in year 5 (Table 128). One year after treatment, stumps averaged six sprouts each, but after 3 years these had thinned to an average of two per stump. Average sprout height was 50 cm 1 year after treatment and 273 cm by year 5. Sprouting was highly variable among sites, depending on the completeness of the glyphosate treatment. Where glyphosate was applied to all cut stumps, there was virtually no sprouting, whereas on the site where many stumps missed glyphosate treatment, about 70% of cut stumps had sprouts.

Richness and diversity of individual species and structural vegetation groups Cut stump–glyphosate treatment of the *Mixed Broadleaf-Shrub* Complex had no effect on either species richness or diversity (p>0.10) (Table 129). Species richness increased considerably between the pre-treatment (18 species) and the third-year assessment (31 species), but increases occurred equally in the treatment and control.

Richness of structural vegetation groups did not differ between the treatment and control on any measurement date (p>0.10) (Table 130). However, diversity of structural groups was significantly greater in the brushing treatment than in the control 3–5 years after cut stump–glyphosate application (p<0.10) (Table 130), likely because of reduced broadleaf dominance in the treatment.

Paper birch was the primary target species on these sites, and its presence decreased dramatically on all three sites following treatment. Reductions in cover persisted for at least 5 years on two of the study sites. On the third site, where treatment was

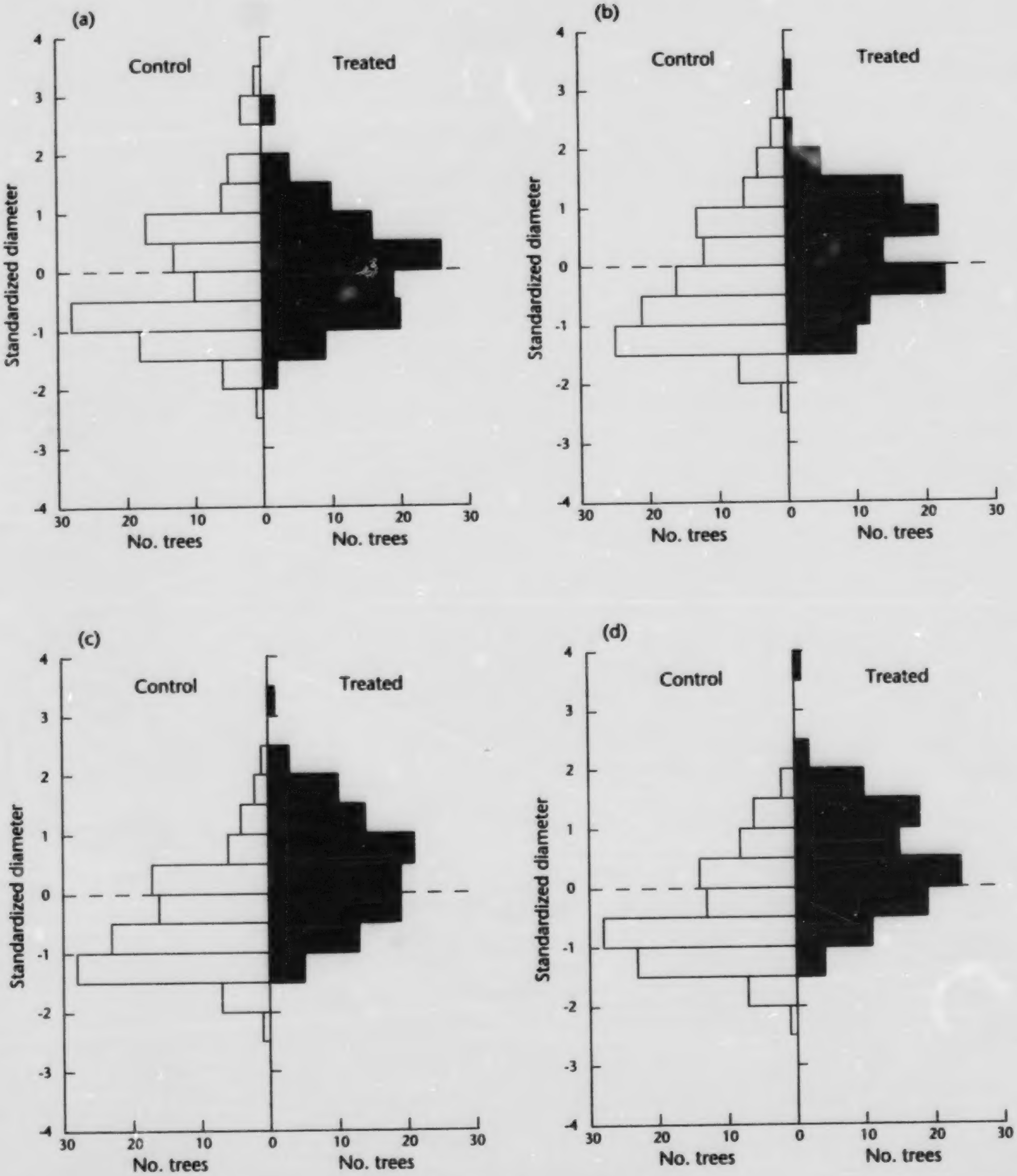

FIGURE 139 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after cut stump–glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

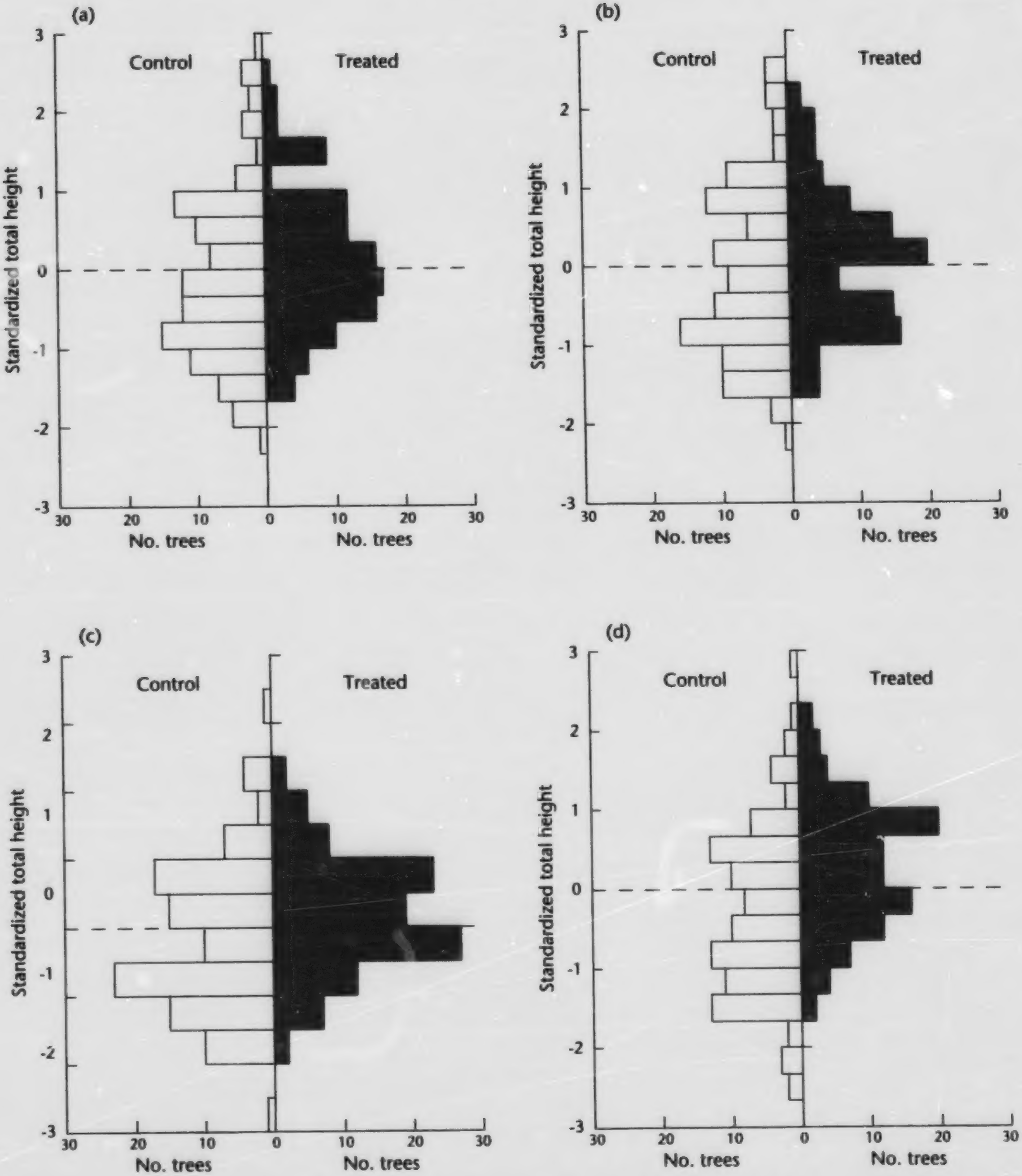

FIGURE 140 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH Mixed Broadleaf-Shrub Complex before and after cut stump–glyphosate treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

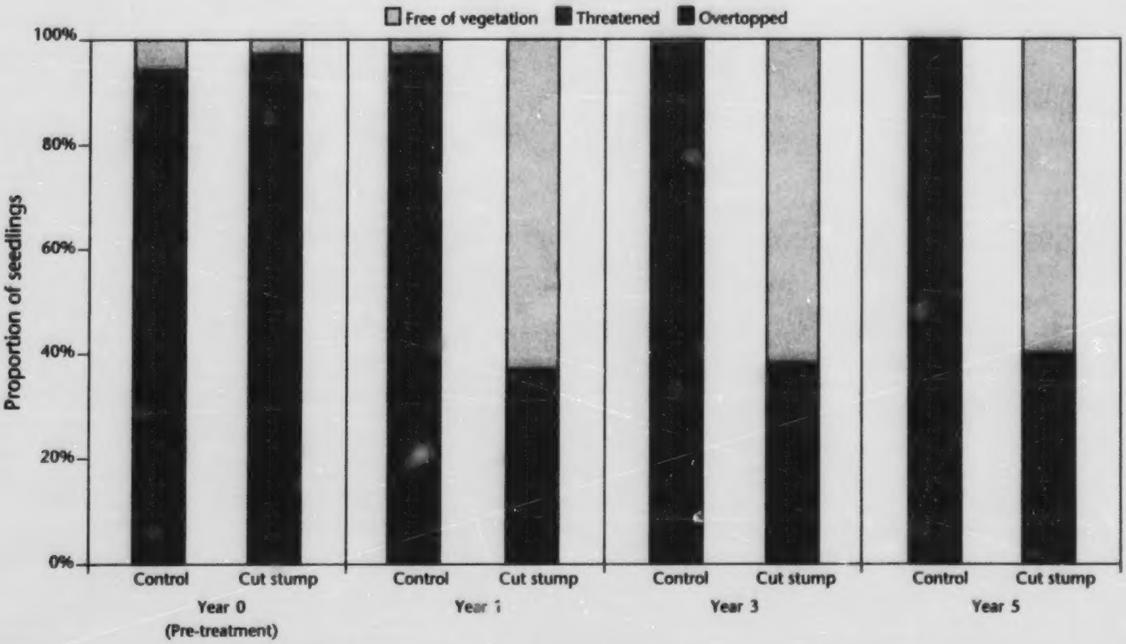

FIGURE 141 *Comparison of Douglas-fir competitive status between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

poorly applied, birch partially recovered, increasing in cover by the fifth-year assessment. Willow either appeared or gradually increased during the 5 years of monitoring in the treated plots but not in the controls.

Herbs showed no tendency to decrease following the cut stump–glyphosate treatment, but several species became more abundant following treatment, likely in response to increased light availability (Table 131). The following herbs increased in abundance in treatment but not control plots on at least two of three sites: fireweed cover gradually increased during the 5-year monitoring period, dandelion appeared or increased in abundance, and strawberry and rattlesnake plantain (*Goodyera oblongifolia*) appeared within 3 years of brushing.

Girdling

Douglas-fir in the ICH zone

This section describes fifth-year Douglas-fir and vegetation responses to girdling of broadleaf stems in the ICH zone *Mixed Broadleaf-Shrub* Complex (n = 3) (Figure 144). Conifers were 5–17 years old at the time of treatment.

Description of study sites and treatments

The three sites in this treatment cell are located throughout the Kamloops Forest Region: at Russell Creek, 22 km northeast of Barriere in the Kamloops District; at Gordon Bay, on the west side of Adams Lake in the Clearwater District; and at Scotch Creek, 20 km north of Sorrento on the north side of Shuswap Lake in the Salmon Arm District. All three sites are in the Thompson Moist Warm ICH variant (ICHmw3).

Two of the sites are mesic (site series 01) in mid- and lower slope positions, and one is mesic–submesic (site series 05) in mid-slope position (Table 132). The sites have southeasterly to easterly aspects with gentle to moderate slopes (5–35%). Soils are loamy (loam to sandy loam) Brunisols. Elevations of the sites range from 520 to 1200 m.

The original stands were clearcut between 1972

TABLE 127 *Cover and height of vegetation in the ICH* Mixed Broadleaf-Shrub *Complex before and after cut stump–glyphosate treatment in Douglas-fir plantations*

	Means			
Response variable	**Cut stump–glyphosate**	**Control**	**Standard error**	**p-value**
All vegetation				
Cover (%)				
Pre-treatment	87.3	87.5	1.177	0.90
1 yr post-treatment	39.8	57.0	7.909	0.26
3 yr post-treatment	70.9	80.3	1.277	0.04*
5 yr post-treatment	78.0	90.5	6.491	0.31
Height (cm)				
Pre-treatment	219.8	363.6	67.881	0.27
1 yr post-treatment	104.3	495.5	45.110	0.03*
3 yr post-treatment	155.7	578.1	73.264	0.06*
5 yr post-treatment	193.9	933.6	155.545	0.08*
Broadleaf trees				
Cover (%)				
Pre-treatment	52.6	54.9	1.663	0.42
1 yr post-treatment	2.7	34.6	12.522	0.21
3 yr post-treatment	9.4	50.3	10.206	0.10*
5 yr post-treatment	15.4	69.6	7.493	0.04*
Height (cm)				
Pre-treatment	427.2	448.0	17.731	0.42
1 yr post-treatment	107.5	556.7	72.320	0.05*
3 yr post-treatment	218.0	692.2	94.518	0.07*
5 yr post-treatment	384.6	952.3	78.360	0.04*
Shrubs				
Cover (%)				
Pre-treatment	41.9	50.2	4.267	0.30
1 yr post-treatment	27.0	29.5	0.550	0.08*
3 yr post-treatment	43.7	51.2	2.505	0.17
5 yr post-treatment	48.1	58.7	2.714	0.11
Shrubs *(continued)*				
Height (cm)				
Pre-treatment	77.6	92.4	7.276	0.29
1 yr post-treatment	75.8	98.4	3.231	0.04*
3 yr post-treatment	91.3	113.2	3.101	0.04*
5 yr post-treatment	112.0	117.9	7.330	0.63
Herbs				
Cover (%)				
Pre-treatment	34.0	25.9	4.748	0.35
1 yr post-treatment	9.4	5.4	2.204	0.33
3 yr post-treatment	17.8	7.7	4.924	0.28
5 yr post-treatment	18.4	7.6	6.754	0.38
Height (cm)				
Pre-treatment	65.5	65.1	2.128	0.92
1 yr post-treatment	94.3	77.5	12.453	0.44
3 yr post-treatment	124.9	90.1	12.905	0.20
5 yr post-treatment	148.4	87.9	21.400	0.18
Paper birch				
Cover (%)				
Pre-treatment	48.2	50.1	1.342	0.42
1 yr post-treatment	2.5	32.8	13.175	0.25
3 yr post-treatment	9.3	46.8	11.162	0.14
5 yr post-treatment	15.3	64.8	8.354	0.05*
Height (cm)				
Pre-treatment	423.3	444.2	14.731	0.42
1 yr post-treatment	123.0	543.0	77.824	0.06*
3 yr post-treatment	227.0	679.7	97.110	0.08*
5 yr post-treatment	376.8	932.2	93.385	0.05*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; $n = 3$. The standard error of the overall mean $(\bar{y})$ was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

and 1978 and each site was prepared within 3 years of harvest. Two sites were mechanically site prepared and one was broadcast burned. Douglas-fir were planted on the sites 1–7 years after site preparation, and the planted trees were 5–17 years old and 1.1–6.5 m tall at the time of brushing. About half the Douglas-fir were overtopped and 17% were free of vegetation. Total conifer stocking ranged from 1125 to 3909 stems/ha, of which 795–1200 stems/ha were well spaced.

Birch, aspen, and cottonwood were present in varying abundances on the three sites. The broadleaf composition varied from pure birch on one site, to a mixture of birch and cottonwood on the second site, to a mixture of aspen and cottonwood with a minor birch component on the third site. The broadleaves tended to be vigorous, and on all sites they were increasing in height at a greater rate (30–75 cm/yr) than the Douglas-fir (20–50 cm/yr). Total broadleaf cover and height averaged 25% and 603 cm, respectively, but ranged from 9 to 41% and 374 to 803 cm. Density of broadleaf trees varied from

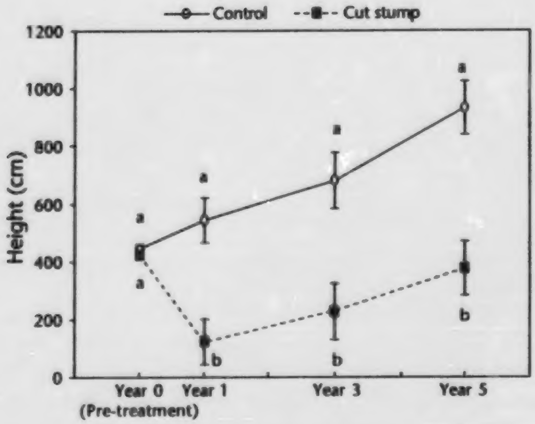

FIGURE 142 *Comparison of mean birch height between the cut stump–glyphosate treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub Complex. *Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance (∝ = 0.10).*

TABLE 128 *Sprouting characteristics of paper birch in the ICH* Mixed Broadleaf-Shrub Complex *following cut stump–glyphosate treatment in Douglas-fir plantations*

Response variable	Mean
Proportion of stumps with sprouts	
1 yr post-treatment	28
3 yr post-treatment	24
5 yr post-treatment	24
Number of sprouts per stump	
1 yr post-treatment	6
3 yr post-treatment	2
5 yr post-treatment	2
Sprout length (cm)	
1 yr post-treatment	50
3 yr post-treatment	134
5 yr post-treatment	273

TABLE 129 *Richness and diversity of vascular plant species in the ICH* Mixed Broadleaf-Shrub Complex *following cut stump–glyphosate treatment in Douglas-fir plantations*

	Means			
Response variable	Cut stump–glyphosate	Control	Standard error	p-value
Richness				
Pre-treatment	16.00	20.00	1.225	0.15
1 yr post-treatment	21.33	24.00	1.247	0.27
3 yr post-treatment	25.00	31.67	2.494	0.20
5 yr post-treatment	28.50	33.00	1.768	0.32
Shannon-Weaver Diversity Index				
Pre-treatment	1.48	1.56	0.030	0.20
1 yr post-treatment	1.82	1.71	0.088	0.47
3 yr post-treatment	1.93	1.73	0.110	0.33
5 yr post-treatment	1.58	1.52	0.068	0.65
Simpson's Diversity Index				
Pre-treatment	0.67	0.69	0.008	0.21
1 yr post-treatment	0.75	0.72	0.011	0.21
3 yr post-treatment	0.77	0.72	0.024	0.26
5 yr post-treatment	0.68	0.65	0.020	0.52

The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$, where MSE = Mean Square Error and n = number of replicates.

1600 to 31 000 stems/ha. The lowest density occurred at Russell Creek, where the trees were larger (8 m tall) than on the other two sites (3–6 m tall).

Brushing took place 14–20 years after harvest and 12–19 years after site preparation. At Russell Creek and Gordon Bay, broadleaves were girdled and smaller vegetation was manually cut (Table 133). At Russell Creek, 350 broadleaves stems/ha were retained, while at Gordon Bay all broadleaves were treated. At Scotch Creek, broadleaves were injected with glyphosate, which had an effect similar to that of girdling.

Conifer response

Survival and vigour Survival of 10- to 22-year-old Douglas-fir (5–17 years old at the time of treatment) was significantly lower in the girdling treatment (90%) than in the control (97%) 5 years after treatment (p = 0.02) (Table 134). *Armillaria ostoyae* was the main mortality agent, and it caused significantly more mortality in the treatment than in the control (8 versus 3%, p = 0.07) (Figure 145). Annual

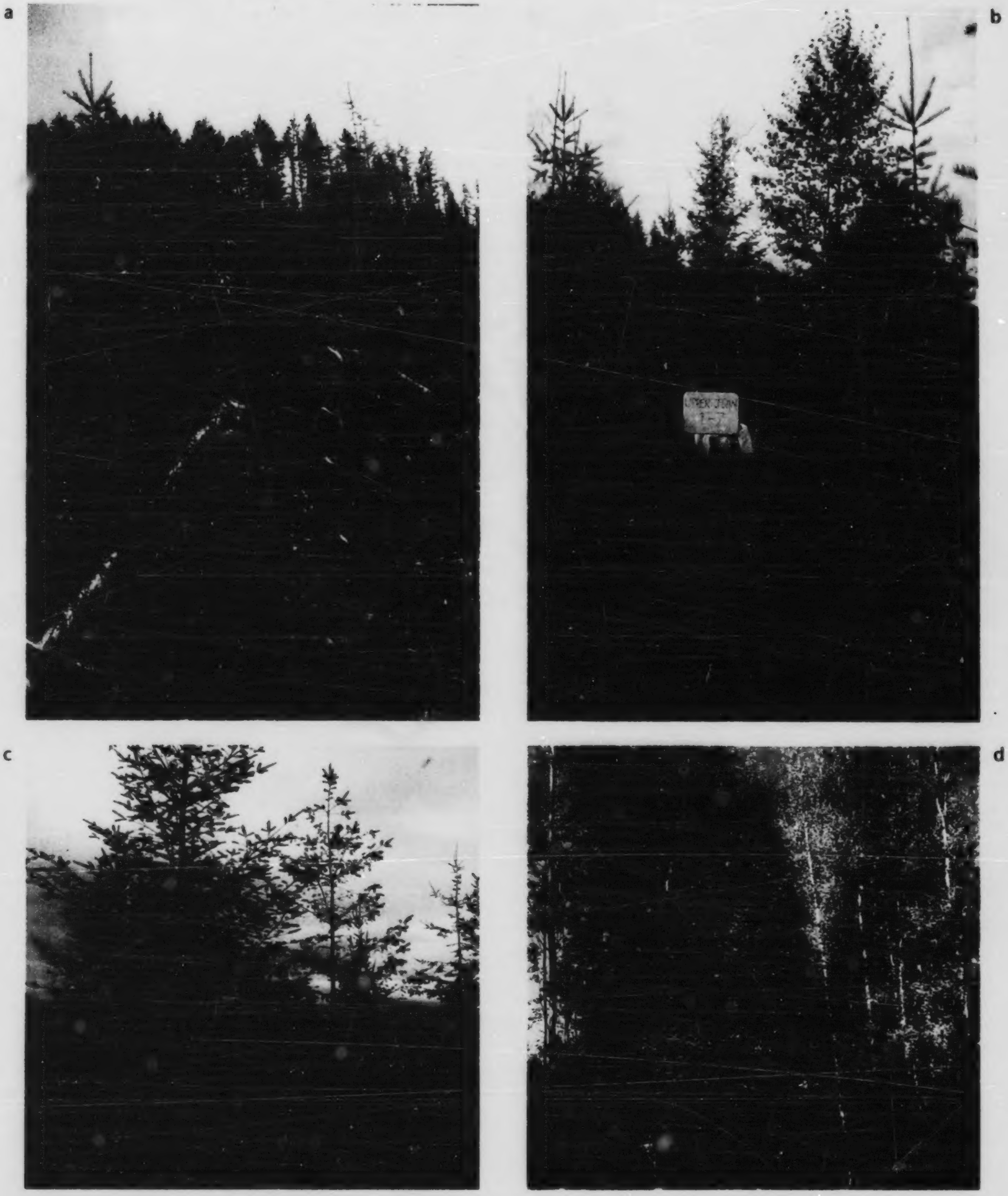

FIGURE 143 *Effects of cut stump–glyphosate treatment on the* Mixed Broadleaf-Shrub *Complex and Douglas-fir (a) 1 year, (b) 3 years and (c) 5 years following treatment. The control (d) is shown 5 years post- treatment for comparison. Photo credit: Jean Mather.*

FIGURE 144 *The* Mixed Broadleaf-Shrub *Complex and Douglas-fir prior to girdling at Gordon Bay (Site 15) in the ICHmw3 variant in the Clearwater Forest District. Photo credit: Silver Ring Forestry Ltd.*

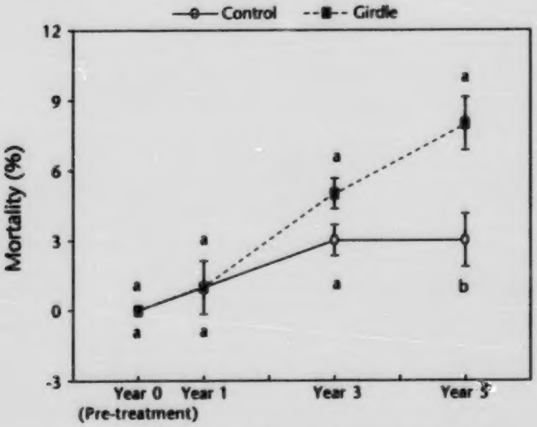

FIGURE 145 *Comparison of mean Douglas-fir mortality due to* Armillaria *between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub Complex. *Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\alpha = 0.10$).*

TABLE 130 *Richness and diversity of structural vegetation groups in the ICH* Mixed Broadleaf-Shrub *Complex following cut stump–glyphosate treatment in Douglas-fir plantations*

	Means			
Response variable	Cut stump–glyphosate	Control	Standard error	p-value
Richness				
Pre-treatment	7.00	7.67	0.471	0.42
1 yr post-treatment	8.00	7.67	0.236	0.42
3 yr post-treatment	7.67	7.67	0.000	1.00
5 yr post-treatment	7.50	7.50	0.707	1.00
Shannon-Weaver Diversity Index				
Pre-treatment	1.20	1.30	0.019	0.06*
1 yr post-treatment	1.45	1.36	0.035	0.20
3 yr post-treatment	1.49	1.37	0.036	0.14
5 yr post-treatment	1.32	1.25	0.007	0.09*
Simpson's Diversity Index				
Pre-treatment	0.61	0.65	0.016	0.26
1 yr post-treatment	0.69	0.67	0.009	0.20
3 yr post-treatment	0.70	0.67	0.001	0.00*
5 yr post-treatment	0.69	0.61	0.002	0.06*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Analysis of covariance was applied where there were pre-treatment differences according to analysis of variance.

rates of mortality from *Armillaria* since brushing were 1.6%/yr in the girdling treatment and 0.6%/yr in the control. The fifth-year silviculture survey, which was conducted according to the old free-growing guidelines (B.C. Ministry of Forests 1995a), indicated there were significantly more free-growing trees in the girdling treatment (370 stems/ha) than the control (166 stems/ha) (p = 0.05).

During the 5-year monitoring period, average vigour of Douglas-fir improved in the girdling treatment and remained constant in the control (Figure 146). The proportion of poor-vigour trees decreased from 24 to 4% in the treatment but remained constant (17–18%) in the control. By year 5, 52% of treated Douglas-fir were of good vigour, compared to 28% of control trees. At one site (Scotch Creek), there was a large decrease in the vigour of Douglas-fir in the first year after treatment because damage from deer and rabbit browsing increased after birch were killed. However, most trees recovered within 2 years.

Growth One year after girdling, Douglas-fir growth did not differ between the girdling treatment and the control ($p>0.10$) (Table 134). Three years after treatment, diameter increment was greater (0.67 versus 0.43 cm, $p = 0.03$) and height:diameter ratio lower (50.2 versus 60.3, $p = 0.08$) (Figure 147) in the treatment than in the control, but there were still no differences in diameter, height, or leader length ($p>0.10$). Five years after girdling, the diameter increment and height:diameter ratio differences had disappeared, and there still were no differences in total height. Leader length was greater in the treatment than in the control in the fifth-year assessment (34.9 versus 22.3 cm, $p = 0.02$) (Figure 148), but the difference was not large enough to significantly affect overall height.

TABLE 131 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following cut stump–glyphosate treatment of the ICH* Mixed Broadleaf-Shrub Complex *in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		*Betula papyrifera*	
Low shrubs	*Ribes lacustre* *Salix* spp.		*Pachistima myrsinites* *Rubus parviflorus*
Herbs	*Epilobium angustifolium* *Fragaria* spp. *Goodyera oblongifolia* *Taraxacum officinale*		

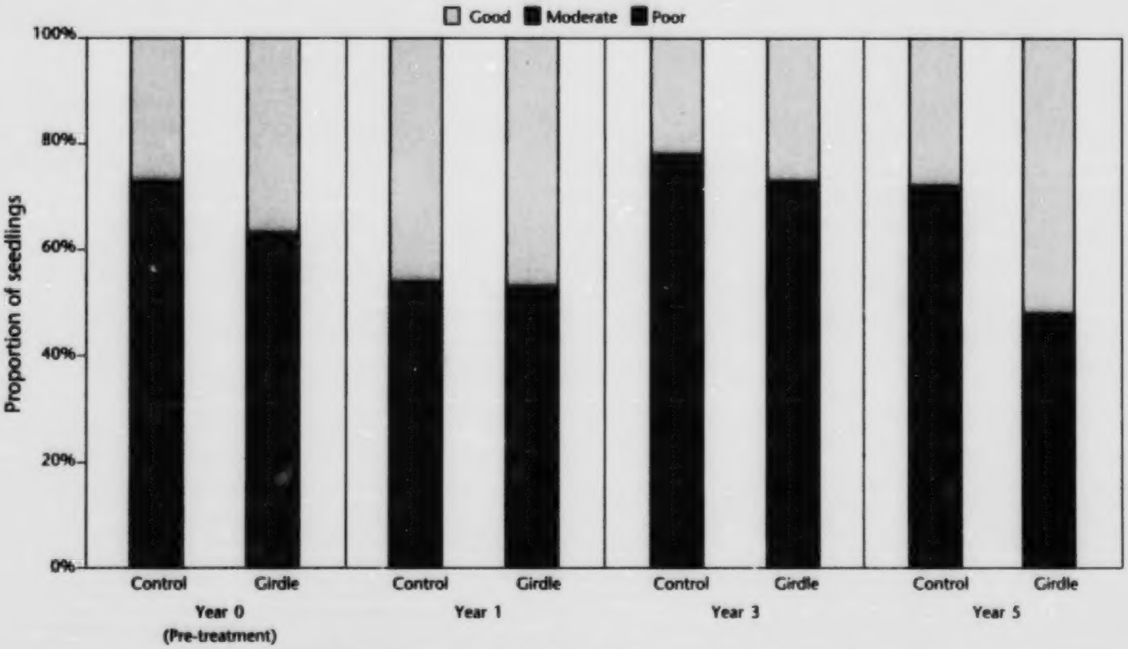

FIGURE 146 *Comparison of Douglas-fir vigour between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub Complex.

TABLE 132 *Characteristics and history of the three replicate study sites where the ICH* Mixed Broadleaf-Shrub *Complex was girdled in Douglas-fir plantations*

	Site characteristics and history							Characteristics of target conifers at PROBE initiation							Conifer stocking (stems/ha)	
Site location	BEC unit	Elev. (m)	Aspect/ slope	Soil class/ texture	Logging and site prep. history	Years since harvest	Years since site prep.	Est. delay[a] (yr)	Origin[b]	Stock	Age[c] (yr)	Height[d] (cm)	Abundance of major vegetation species: cover (%) and height[d] (cm)		Total	Well spaced
Russell Creek PROBE 30 Kamloops District	ICHmw3 05 (mesic–submesic)	1200	E 5%	Brunisol/ sandy loam	Clearcut 1972 Burned 1973	21	20	3	P 1974	1+0 plug	17	654 (147)	Aspen cover: 5 (3) Aspen height: 823 (260) Cottonwood cover: 3 (3) Cottonwood ht: 555 (271) Willow cover: 4 (2) Willow height: 486 (567)		1125	795
Gordon Bay PROBE 15 Clearwater District	ICHmw3 01 (mesic)	520	SE 15%	Brunisol/ sandy loam	Clearcut 1977 MSP 1980	14	12	5	P 1985	PSB 313 1+0	7	116 (47)	Birch cover: 39 (22) Birch height: 663 (209)		2499	798
Scotch Creek PROBE 21 Salmon Arm District	ICHmw3 01 (mesic)	880	SE 35%	Brunisol/ loam	Clearcut 1978 MSP 1980	14	12	7	P 1987	PSB 313 1+0	5	107 (38)	Birch cover: 17 (10) Birch height: 470 (794) Cottonwood cover: 6 (5) Cottonwood ht: 241 (115)		3909	1200

[a] Establishment delay refers to the number of years between the last disturbance (e.g., harvest or site preparation) and planting
[b] Origin: P = planted; N = natural regeneration
[c] Age refers to the number of years since planting
[d] Values are means and one standard deviation (in parentheses)

TABLE 133 *A description of girdling treatments applied to the three replicate study sites to release Douglas-fir seedlings growing in the ICH* Mixed Broadleaf-Shrub *Complex*

Site	Treatment date	Broadleaf retention (stems/ha)	Treatment tool	Treatment specification
Russell Creek	August 1993	350	Chain girdler	Broadleaves >5 cm diameter girdled; smaller broadleaves and willow cut near ground level. Treatment done within 2-m radius of healthy conifers (not done around conifers with *Armillaria* symptoms). Girdling was the dominant treatment.
Gordon Bay	August 1993	0	Chain girdler	All birch girdled; cottonwood, aspen, cherry, willow, and other large shrubs cut near ground level.
Scotch Creek	Mid-October 1992	0	E-Z-JECT injector	Broadleaves >1 cm diameter injected with glyphosate (0.15 g per 5-cm stem). Stems <1 cm diameter not treated.

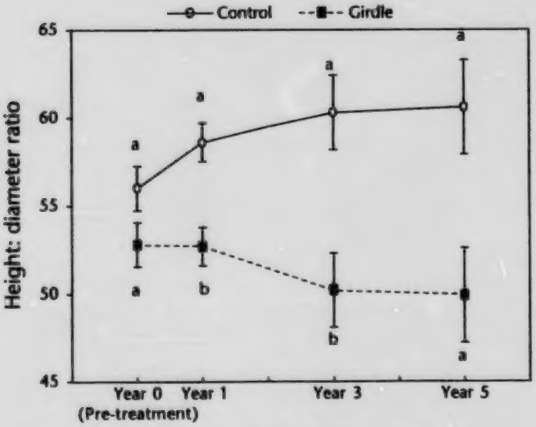

FIGURE 147 *Comparison of mean Douglas-fir height:diameter ratio between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub Complex. *Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\propto = 0.10$).*

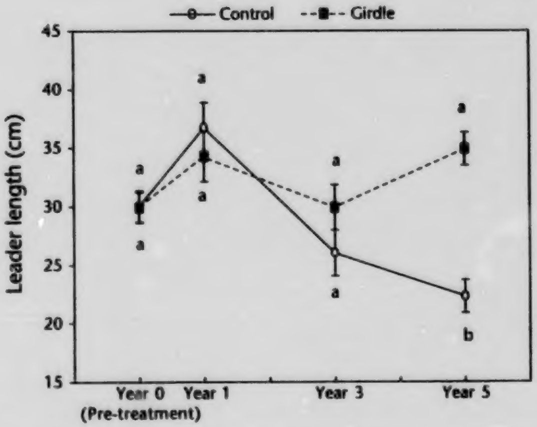

FIGURE 148 *Comparison of mean Douglas-fir leader length between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub Complex. *Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\propto = 0.10$).*

TABLE 134 *Survival and growth responses of Douglas-fir seedlings to girdling in the ICH Mixed Broadleaf-Shrub Complex*

Response variable	Means		Standard error	p-value
	Girdling	Control		
Survival (%)				
Pre-treatment	100	100	0.000	1.00
1 yr post-treatment	99	99	1.135	1.00
3 yr post-treatment	95	97	0.000	0.00*
5 yr post-treatment	90	97	0.653	0.02*
Mortality due to Armillaria (%)				
Pre-treatment	0	0	0.000	1.00
1 yr post-treatment	1	1	1.135	1.00
3 yr post-treatment	5	3	0.654	0.18
5 yr post-treatment	8	3	1.133	0.07*
Stem diameter (cm)				
Pre-treatment	6.55	5.93	0.468	0.44
1 yr post-treatment	7.98	6.84	0.697	0.37
3 yr post-treatment	9.28	7.65	0.665	0.22
5 yr post-treatment	10.71	8.68	0.518	0.11
Diameter increment (cm)				
1 yr post-treatment	0.97	0.67	0.099	0.14
3 yr post-treatment	0.67	0.43	0.027	0.03*
5 yr post-treatment	0.71	0.54	0.058	0.18
Height (cm)				
Pre-treatment	297.9	286.3	13.250	0.62
1 yr post-treatment	361.3	351.4	12.726	0.64
3 yr post-treatment	427.6	406.9	13.064	0.38
5 yr post-treatment	495.8	451.9	14.580	0.17
Leader length (cm)				
Pre-treatment	29.9	30.0	1.341	0.96
1 yr post-treatment	34.3	36.7	2.201	0.52
3 yr post-treatment	29.9	26.0	1.949	0.29
5 yr post-treatment	34.9	22.3	1.388	0.02*
Height:diameter ratio				
Pre-treatment	52.8	56.0	1.277	0.21
1 yr post-treatment	52.7	58.6	1.094	0.06*
3 yr post-treatment	50.2	60.3	2.118	0.08*
5 yr post-treatment	49.9	60.6	2.678	0.11

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

Standardized stem diameter distributions for Douglas-fir were more or less normal in both the treatment and control prior to the girdling treatment, but by year 5, there was a noticeable increase in the frequency of treated trees in larger diameter classes (Figure 149). ANOVA showed that differences between the treatment and the control were not statistically significant during the 5-year measurement period, but the distributions suggest that the difference may become more pronounced in future assessments. Standardized height distributions were approximately normal in the treatment and control, and they changed very little during the 5-year assessment period (Figure 150). This is consistent with ANOVA results showing that Douglas-fir did not become taller as a result of broadleaf girdling.

Competitive status Girdling gradually decreased overtopping of Douglas-fir seedlings, but, after 5 years, only half of the treated trees were free of vegetation and one-quarter were still overtopped (Figure 151). The percentage of trees in the treatment that were free of vegetation increased from 15% before treatment to 24% in year 1 and 48% in year 5. The percentage that were overtopped decreased from 50% before treatment to 21% in year 1, and that proportion remained constant through year 5. In the control, the competitive status of Douglas-fir did not change during the 5-year monitoring period (roughly one-fifth were free of vegetation, one-fifth were threatened, and three-fifths were overtopped).

Plant community response

Abundance Girdling killed almost all (>95%) treated broadleaf trees, greatly reducing broadleaf cover in comparison with the control (28.4 versus 9.2, p = 0.09 in year 1) (Table 135). The effects on cover were highly variable, however, and differences between the treatment and control were not significant in years 3 and 5, even though the average cover values in the treatment and control changed very little between the two assessments. By year 5, broadleaf cover was 9.7% in the girdling treatment compared with 34.5% in the control (p = 0.18) (Table 135, Figures 153 and 154).

Girdling did not have a large effect on modal broadleaf height because a few trees escaped treatment and because girdled trees died slowly. After 1 year, broadleaf height was 610.2 cm in the treatment compared with 621.2 cm in the control (p>0.10). Although broadleaf height increased to 843.7 cm in

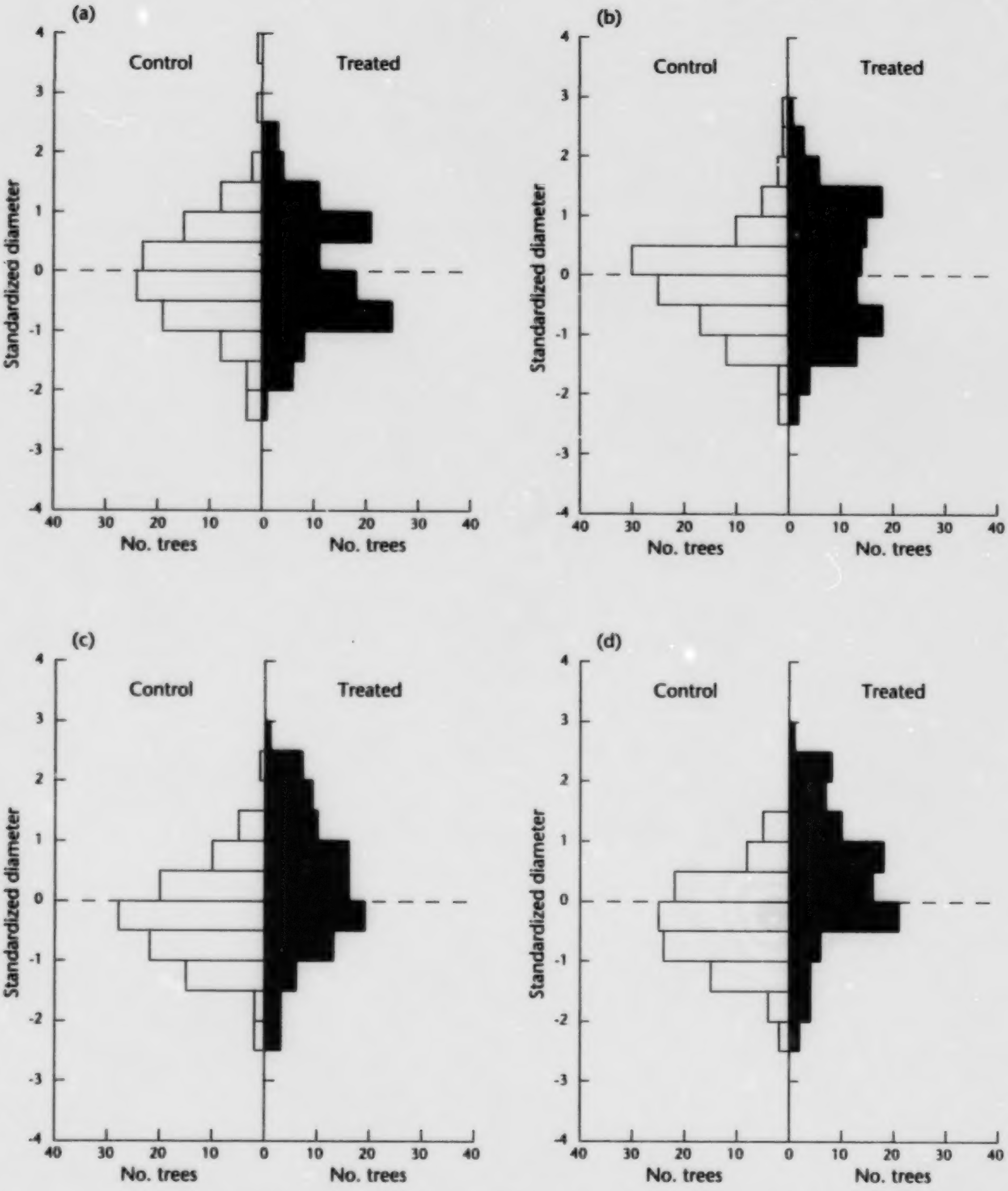

FIGURE 149 *Frequency of control and treated trees in standardized diameter classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH* Mixed Broadleaf-Shrub *Complex before and after girdling treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

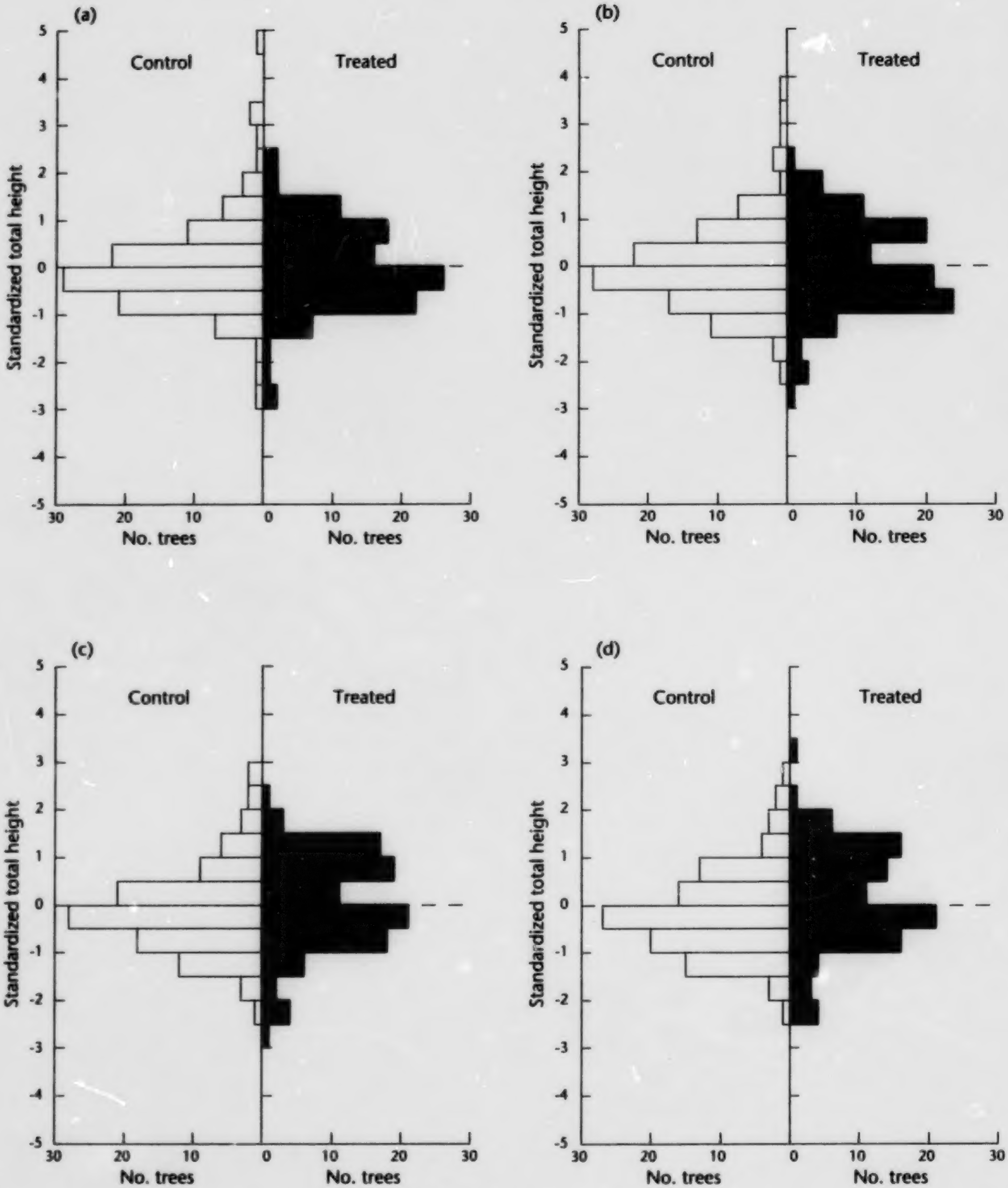

FIGURE 150 *Frequency of control and treated trees in standardized total height classes (μ = 0; s.d. = 1; n = 3 for the control and treatment combined) for Douglas-fir in the ICH* Mixed Broadleaf-Shrub *Complex before and after girdling treatment. Graphs are for: (a) pre-treatment; (b) 1 year post-treatment; (c) 3 years post-treatment; (d) 5 years post-treatment.*

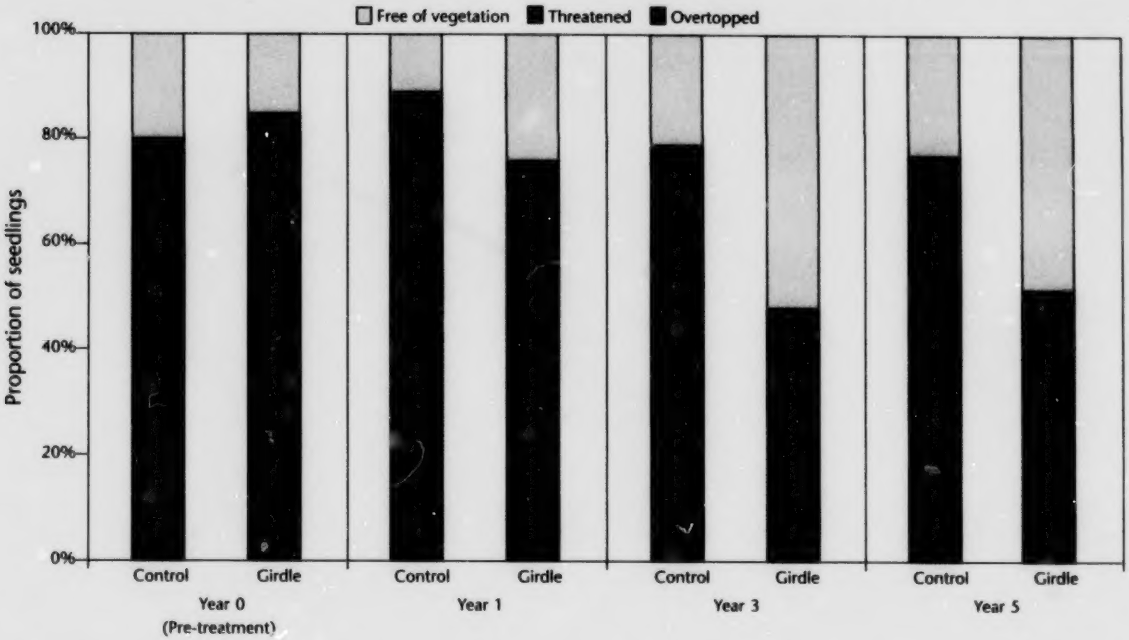

FIGURE 151 *Comparison of Douglas-fir competitive status between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Seedlings were classified as free of vegetation when the leader was well above surrounding vegetation, and classified as overtopped when the leader was overtopped. Threatened seedlings had leaders at approximately the same height as surrounding vegetation.*

the control and decreased slightly to 569.1 cm in the treatment during the 5-year monitoring period, large variability between sites prevented the differences from being statistically significant ($p>0.10$) (Figure 153). Brushing did not affect height or cover of understorey herbs and shrubs ($p>0.10$).

Sprouting Few stems sprouted following girdling or injection of broadleaf trees with glyphosate. Three percent of treated stems had sprouts after 1 year and 11% had sprouts after 5 years. The stems that sprouted had an average of five sprouts that averaged 8 cm tall in year 1 and these thinned to two sprouts that averaged 205 cm tall by year 5 (Table 136).

Richness and diversity of individual species and structural vegetation groups Girdling of broadleaf stems had no effect on species richness in the *Mixed Broadleaf-Shrub* Complex ($p>0.10$) (Table 137). The number of species increased between the pre-treatment (38 species) and fifth-year assessments (49 species), but the increase occurred equally in the girdling treatment and control. Girdling resulted in slightly greater species diversity compared with the control 1 year after brushing ($p = 0.07$ for H, $p = 0.03$ for SDI), but the difference had disappeared by year 3 ($p>0.10$).

The richness of structural vegetation groups was similar in the girdling treatment and control throughout the 5-year monitoring period ($p>0.10$) (Table 138), but diversity of structural groups was slightly greater in the control than in the girdling treatment 1 and 5 years after treatment ($p<0.10$).

Girdling caused large decreases in the cover of paper birch, which was the main brushing target, on two of the three study sites. Partial reductions were apparent 1 year after treatment, but girdled stems died gradually, and the full impact on birch cover was not expressed until the third year after treatment. Trembling aspen and black cottonwood were also present on two of the three sites, and their cover decreased in a similar manner to birch over the 5-year monitoring period (Table 139). Cover of individual shrub and herb species did not decrease on more than one site, and although total herb cover increased on all sites following girdling, dandelion was the only species that increased on more than one site.

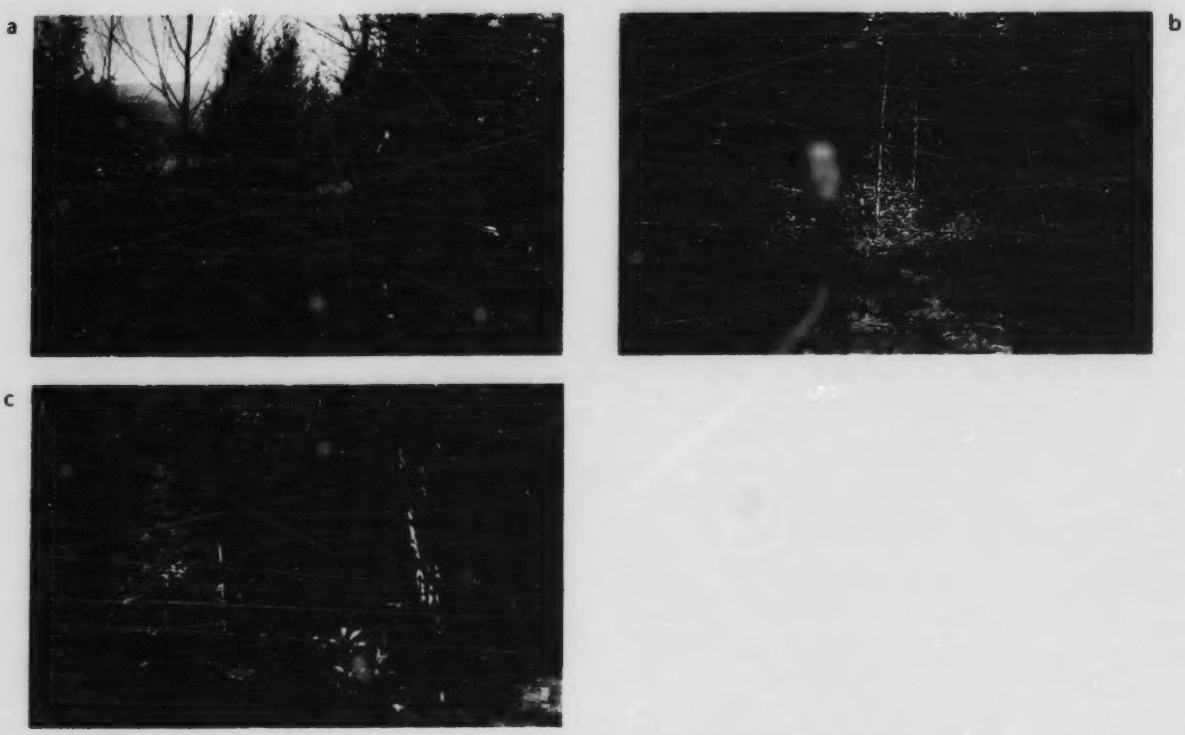

FIGURE 152 *Effects of girdling on the* Mixed Broadleaf-Shrub *Complex and Douglas-fir (a) 1 year and (b) 5 years following treatment. The control (c) is shown 5 years post-treatment for comparison. Photo credit: Silver Ring Forestry Ltd.*

Competition Thresholds for Douglas-fir, Lodgepole Pine, and Hybrid Spruce

Competition thresholds were derived for stem diameter of Douglas-fir, lodgepole pine, and interior spruce using all PROBE plantations dominated by the *Mixed Broadleaf-Shrub* Complex. For Douglas-fir, four sites were manually cut, three were treated with cut stump–glyphosate, three were girdled, and four were treated with other chemical applications (n = 14). For lodgepole pine, the analysis included two sites that were manually brushed and one that received a glyphosate spray treatment (n = 3). For interior spruce, two sites were manually cut and one was sprayed with glyphosate (n = 3). Amost all sites occurred in the ICH zone, and a few occurred in wetter subzones of the IDF zone (see site descriptions in this section and in Appendix 2). The range in plantation ages was 2–17 years for Douglas-fir (Table 140), 3–11 years for lodgepole pine (Table 141), and 1–13 years for interior spruce (Table 142). Thresholds were based on broadleaf density (stems/ha), percent cover, and the index CRH, where CRH = (broadleaf cover * modal broadleaf height)/seedling height. The dominant broadleaf species was paper birch.

The density thresholds for Douglas-fir (Table 140), lodgepole pine (Table 141), and interior spruce (Table 142) stem diameter averaged 3664, 3367, and 2500 stems/ha, respectively. Cover thresholds averaged 28, 18, and 20%, and CRH thresholds averaged 39, 15, and 27, for Douglas-fir, lodgepole pine, and interior spruce, respectively. There were no clear trends in threshold changes with plantation age. Density and cover thresholds for all conifer species were diffuse on most sites and sharp on a few; however, conifer stem diameter consistently decreased above the threshold values. In contrast, CRH thresholds were sharp on most sites. Below all thresholds, conifer diameter was highly variable (e.g., Figure 155).

The proportion of conifers that occurred above

TABLE 135 *Cover and height of vegetation in the ICH* Mixed Broadleaf-Shrub *Complex before and after girdling in Douglas-fir plantations*

Response variable	Means		Standard error	p-value
	Girdling	Control		
All vegetation				
Cover (%)				
Pre-treatment	77.7	79.9	2.182	0.54
1 yr post-treatment	85.8	88.6	0.665	0.10*
3 yr post-treatment	86.7	90.0	1.987	0.36
5 yr post-treatment	87.8	91.7	1.017	0.11
Height (cm)				
Pre-treatment	547.1	511.7	51.110	0.67
1 yr post-treatment	214.1	494.0	57.205	0.07*
3 yr post-treatment	137.9	597.8	107.307	0.09*
5 yr post-treatment	456.9	736.7	73.414	0.11
Broadleaf trees				
Cover (%)				
Pre-treatment	22.7	26.3	1.893	0.32
1 yr post-treatment	9.2	28.4	4.499	0.09*
3 yr post-treatment	7.9	32.9	6.545	0.11
5 yr post-treatment	9.7	34.5	8.828	0.18
Height (cm)				
Pre-treatment	648.6	559.4	24.463	0.12
1 yr post-treatment	610.2	621.2	92.878	0.94
3 yr post-treatment	544.6	803.8	123.279	0.28
5 yr post-treatment	569.1	843.7	121.244	0.25
Shrubs				
Cover (%)				
Pre-treatment	27.4	30.0	3.073	0.61
1 yr post-treatment	43.9	54.7	6.015	0.33
3 yr post-treatment	54.9	58.7	3.352	0.51
5 yr post-treatment	no data	no data		
Height (cm)				
Pre-treatment	103.2	117.2	17.730	0.63
1 yr post-treatment	82.4	130.9	22.493	0.27
3 yr post-treatment	83.2	108.8	11.192	0.25
5 yr post-treatment	no data	no data		
Herbs				
Cover (%)				
Pre-treatment	34.8	32.7	2.266	0.59
1 yr post-treatment	44.6	27.1	4.494	0.11
3 yr post-treatment	47.9	30.4	2.568	0.04*
5 yr post-treatment	45.2	36.1	7.639	0.49
Height (cm)				
Pre-treatment	83.8	104.8	18.860	0.51
1 yr post-treatment	56.9	48.9	6.870	0.50
3 yr post-treatment	51.4	69.3	11.937	0.40
5 yr post-treatment	56.2	42.0	6.919	0.28

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 136 *Sprouting characteristics of paper birch in the ICH* Mixed Broadleaf-Shrub *Complex following girdling in Douglas-fir plantations*

Response variable	Mean
Proportion of stumps with sprouts	
1 yr post-treatment	3
3 yr post-treatment	14
5 yr post-treatment	11
Number of sprouts per stump	
1 yr post-treatment	5
3 yr post-treatment	7
5 yr post-treatment	2
Sprout length (cm)	
1 yr post-treatment	8
3 yr post-treatment	78
5 yr post-treatment	205

the density thresholds (stems/ha) was 19–37% of all trees (treated and control), 20–39% of control trees, and 15–51% of treated trees. More than half the treated trees (45–85%) and half the control trees (49–80%) fell below the density thresholds. For cover and CRH indices, 29–39% of all trees, 51–62% of control trees, and 2–20% of treated trees occurred above the thresholds. Most treated trees fell below the cover and CRH thresholds (82–98%), whereas less than half the control trees (37–49%) fell below them. These results suggest that conifer response was more sensitive to overall broadleaf cover and height relations than to numbers of individual broadleaf neighbours (i.e., conifer diameter declined at relatively low levels of broadleaf cover and CRH, but was insensitive to a wide range in broadleaf densities). The higher density thresholds did not reflect the increase in number of individual broadleaf stems following manual cutting because density thresholds were derived using control plots only.

Brushing was successful at reducing broadleaf cover and CRH below the thresholds for most treated conifers. Most untreated conifers occurred above the cover and CRH thresholds, although many also naturally occurred in competitive environments below the thresholds. In contrast, only half the treated trees fell below the density thresholds. Cut stump–glyphosate and, to a much lesser degree, manual treatments significantly improved mean diameter as well as diameter distributions of Douglas-fir, whereas girdling had no significant effect. Manual cutting improved lodgepole pine mean diameter and diameter distributions to a greater degree than it did for Douglas-fir. On average, 9% of treated pine and 6% of treated Douglas-fir that were growing in neighbourhoods below the thresholds achieved ≥80% of the maximum diameter measured on the sites. The effects of manual cutting and glyphosate spray on spruce diameter distributions appeared variable, and effects on mean diameter could not be statistically evaluated because of inadequate replication. Approximately 10% of treated spruce growing in neighbourhoods below the thresholds achieved ≥80% of the maximum diameter measured on the sites.

Linear regressions of Douglas-fir diameter versus competition index were statistically significant on nine of 14 sites for broadleaf cover, seven of 14 sites for broadleaf density, and all sites for CRH ($p<0.10$) (Table 140). The range in adjusted r^2 values was 0.04–0.43 for broadleaf density, 0.03–0.46 for broadleaf cover, and 0.05–0.46 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for broadleaf cover (-0.001 to -0.094), very shallow for broadleaf density (0 to -0.002), and shallow to steep for CRH (-0.003 to -0.137) compared with other complexes.

Regressions were similar for lodgepole pine and interior spruce. Linear regressions were statistically significant on two-thirds of the sites for broadleaf cover and density, and all sites for CRH ($p<0.10$). The range in adjusted r^2 values was 0.02–0.31 for broadleaf cover, 0.01–0.18 for broadleaf density, and 0.06–0.36 for CRH (significant regressions only). The slopes of the regressions (β_1) were moderately steep for broadleaf cover (-0.016 to -0.049), flat for broadleaf density (0), and shallow to moderate for CRH (-0.006 to -0.040) compared with other complexes. Fitting a negative exponential function to the diameter-CRH relationships did not improve the adjusted r^2 values. These results suggest that broadleaf competition, as measured by all of the indices, is moderately important and moderately intense for Douglas-fir, lodgepole pine, and interior spruce.

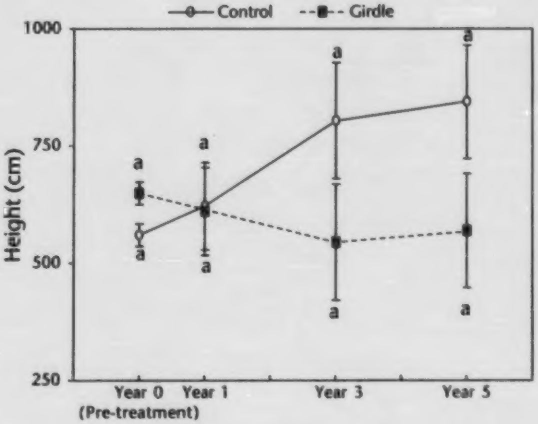

FIGURE 153 *Comparison of mean broadleaf height between the girdling treatment and control before, and 1, 3, and 5 years after, treatment of the ICH* Mixed Broadleaf-Shrub *Complex. Error bars represent one standard error of the mean ($\bar{y}$) which was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates. Means with different letters within a single year are significantly different according to analysis of variance ($\propto = 0.10$).*

FIGURE 154 *Canopy of* Mixed Broadleaf-Shrub *in (a) the treatment and (b) the control 5 years following girdling. Photo credit: Silver Ring Forestry Ltd.*

TABLE 137 *Richness and diversity of vascular plant species in the ICH* Mixed Broadleaf-Shrub *Complex before and after girdling in Douglas-fir plantations*

	Means			
Response variable	**Girdling**	**Control**	**Standard error**	**p-value**
Richness				
Pre-treatment	36.00	40.33	1.312	0.14
1 yr post-treatment	47.33	48.00	2.321	0.86
3 yr post-treatment	49.67	43.67	5.888	0.55
5 yr post-treatment	46.50	52.50	0.707	0.11
Shannon-Weaver Diversity Index				
Pre-treatment	2.43	2.37	0.053	0.52
1 yr post-treatment	2.44	2.34	0.021	0.07*
3 yr post-treatment	2.33	2.28	0.148	0.82
5 yr post-treatment	2.37	2.47	0.086	0.55
Simpson's Diversity Index				
Pre-treatment	0.86	0.84	0.013	0.29
1 yr post-treatment	0.85	0.82	0.004	0.03*
3 yr post-treatment	0.83	0.82	0.022	0.80
5 yr post-treatment	0.84	0.86	0.008	0.42

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 138 *Richness and diversity of structural vegetation groups in the ICH* Mixed Broadleaf-Shrub *Complex before and after girdling in Douglas-fir plantations*

	Means			
Response variable	**Girdling**	**Control**	**Standard error**	**p-value**
Richness				
Pre-treatment	7.67	8.00	0.236	0.42
1 yr post-treatment	7.67	8.00	0.236	0.42
3 yr post-treatment	7.67	8.00	0.236	0.42
5 yr post-treatment	7.50	8.00	0.354	0.50
Shannon-Weaver Diversity Index				
Pre-treatment	1.63	1.64	0.030	0.81
1 yr post-treatment	1.57	1.59	0.002	0.02*
3 yr post-treatment	1.50	1.59	0.051	0.36
5 yr post-treatment	1.55	1.68	0.010	0.07*
Simpson's Diversity Index				
Pre-treatment	0.77	0.76	0.011	0.80
1 yr post-treatment	0.75	0.74	0.003	0.19
3 yr post-treatment	0.72	0.75	0.020	0.43
5 yr post-treatment	0.74	0.78	0.001	0.04*

p-values denoted with "*" were significant at $p \leq 0.10$ according to analysis of variance; n = 3. The standard error of the overall mean ($\bar{y}$) was calculated as $S_{\bar{y}} = \sqrt{MSE/n}$ where MSE = Mean Square Error and n = number of replicates.

TABLE 139 *Vascular plant species that exhibited trends of increasing cover, decreasing cover, or no change in cover following girdling of the ICH* Mixed Broadleaf-Shrub *Complex in Douglas-fir plantations. Species included in the list exhibited a common trend in the treated plots of at least two study sites, based on a subjective evaluation (see Methods, Section 3).*

	Increasing cover	Decreasing cover	No change in cover
Broadleaves		*Betula papyrifera* *Populus tremuloides* *Populus trichocarpa*	
Tall shrubs			*Salix* spp.
Low shrubs			*Ribes lacustre* *Spirea betulifolia*
Herbs	*Taraxacum officinale*		*Anaphalis margaritacea* *Cornus canadensis* *Disporum hookeri* *Galium triflorum* *Hieracium albiflorum* *Orthilia secunda*

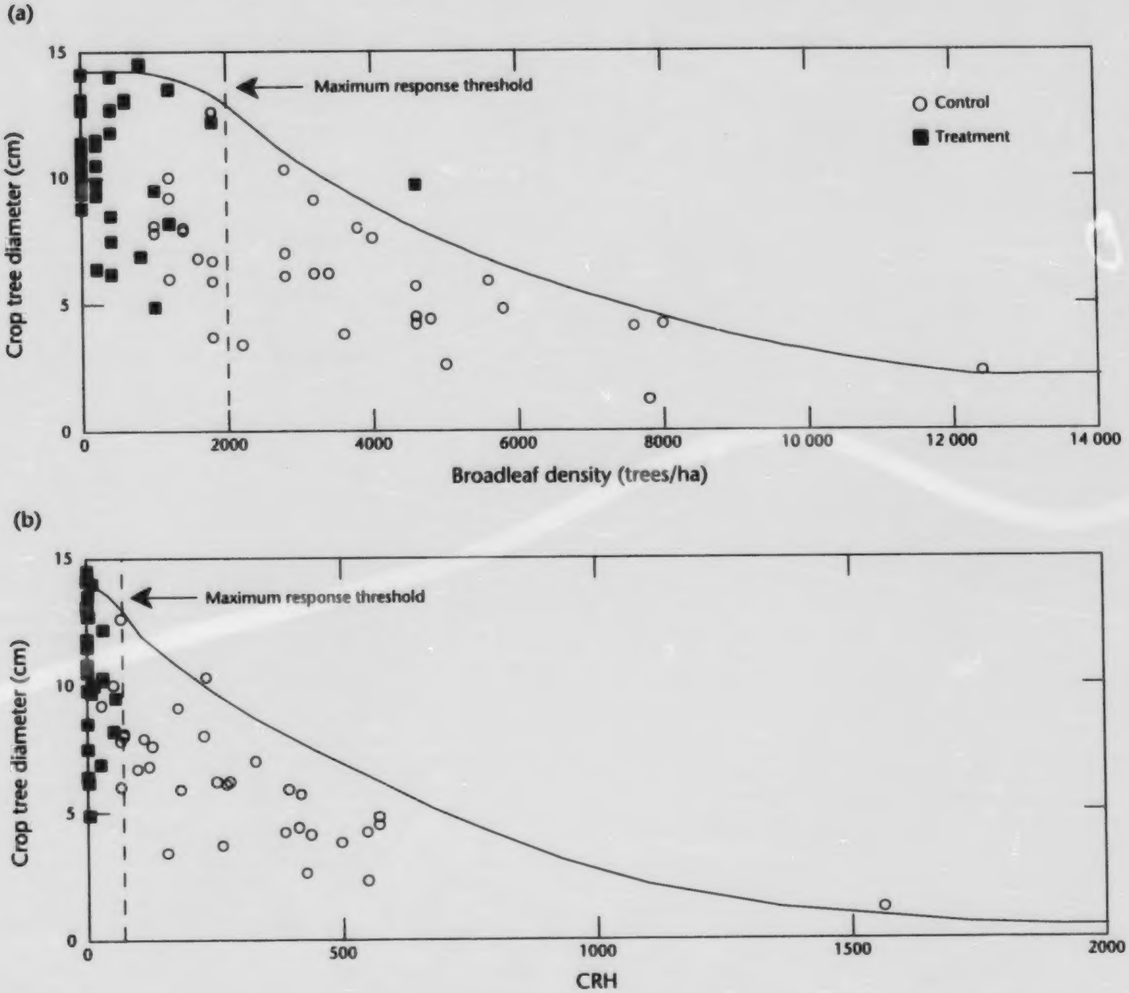

FIGURE 155 *Relationship between stem diameter of Douglas-fir growing amongst the ICH* Mixed Broadleaf-Shrub *Complex and (a) broadleaf density or (b) CRH, where CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir height. Data points include both treatment and control subplots for PROBE site 2 (n = 68). Similar relationships were found for lodgepole pine and hybrid spruce. Maximum response threshold is the point below which conifer diameter is independent of decreasing neighbourhood abundance, and above which conifer performance declines sharply in response to increasing neighbourhood abundance (after Wagner et al. 1989).*

TABLE 140 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Douglas-fir stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the Mixed Broadleaf-Shrub Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density[a]	Adjusted r^2 for linear regression predicting diameter from broadleaf density[a]	p-value for linear regression predicting diameter from broadleaf density[a]	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover[a]
1	70	7	12000	$y = 5.301 - 0.000\,x$	0.08	0.01	35	$y = 5.776 - 0.022\,x$
2	68	12	2000	$y = 10.237 - 0.001\,x$	0.43	0.00	10	$y = 10.538 - 0.065\,x$
3	70	6	2000	$y = 3.983 - 0.000\,x$	0.00	0.95	15	$y = 4.294 - 0.019\,x$
7	68	7	3500	$y = 6.888 - 0.000\,x$	0.10	0.01	20	$y = 7.211 - 0.026\,x$
12	50	6	3200	$y = 6.502 - 0.000\,x$	0.00	0.37	25	$y = 7.271 - 0.032\,x$
15	65	7	1700	$y = 3.987 - 0.000\,x$	0.05	0.05	15	$y = 4.451 - 0.024\,x$
21	70	5	2300	$y = 4.172 - 0.000\,x$	0.00	0.41	25	$y = 4.607 - 0.029\,x$
29	70	6	5000	$y = 4.252 - 0.000\,x$	0.00	0.91	50	$y = 5.399 - 0.026\,x$
30	67	17	3200	$y = 22.932 - 0.002\,x$	0.07	0.02	20	$y = 22.475 - 0.094\,x$
62	70	2	2700	$y = 1.450 - 0.000\,x$	0.00	0.37	10	$y = 1.520 - 0.002\,x$
68	72	8	2900	$y = 3.155 - 0.000\,x$	0.00	0.69	50	$y = 3.197 - 0.001\,x$
69	106	9	2000	$y = 4.956 - 0.000\,x$	0.00	0.32	50	$y = 4.970 - 0.024\,x$
86	107	3	7000	$y = 6.291 - 0.000\,x$	0.04	0.02	45	$y = 7.267 - 0.035\,x$
126	70	7	1800	$y = 3.112 - 0.000\,x$	0.06	0.03	15	$y = 3.049 - 0.033\,x$
mean			3664				28 (4)	
(s.e.)			(748)					

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[a] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\,x$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (broadleaf cover * broadleaf modal height)/Douglas-fir total height.

[c] General form of non-linear equation is $y = a\,e^{(b\,x)}$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 140 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover[a]	p-value for linear regression predicting diameter from broadleaf cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
0.03	0.07	20	$y = 5.995 - 0.009\,x$	0.33	0.00		
0.46	0.00	30	$y = 9.702 - 0.009\,x$	0.46	0.00		
0.01	0.23	45	$y = 4.407 - 0.006\,x$	0.19	0.00		
0.17	0.00	41	$y = 7.049 - 0.009\,x$	0.34	0.00		
0.11	0.01	20	$y = 7.258 - 0.019\,x$	0.29	0.00	$y = 7.439\,e^{(-0.003 * x)}$	0.31
0.20	0.00	16	$y = 4.312 - 0.005\,x$	0.30	0.00		
0.08	0.01	36	$y = 4.496 - 0.007\,x$	0.17	0.00		
0.06	0.02	50	$y = 5.362 - 0.009\,x$	0.38	0.00		
0.00	0.33	30	$y = 23.851 - 0.137\,x$	0.09	0.00		
0.00	0.85	24	$y = 1.667 - 0.003\,x$	0.05	0.07		
0.00	0.91	110	$y = 3.531 - 0.003\,x$	0.06	0.01		
0.01	0.18	58	$y = 5.045 - 0.024\,x$	0.12	0.00		
0.14	0.00	50	$y = 6.955 - 0.011\,x$	0.46	0.02		
0.09	0.01	14	$y = 2.905 - 0.003\,x$	0.18	0.00		
		39 (6)					

TABLE 141 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting lodgepole pine stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the* Mixed Broadleaf-Shrub *Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density[a]	Adjusted r^2 for linear regression predicting diameter from broadleaf density[a]	p-value for linear regression predicting diameter from broadleaf density[a]	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover[a]
46	70	3	6000	$y = 4.414 - 0.000x$	0.10	0.02	22	$y = 4.382 - 0.017x$
41	67	11	1300	$y = 9.310 - 0.000x$	0.01	0.21	15	$y = 11.013 - 0.049x$
51	68	5	2800	$y = 5.207 - 0.000x$	0.18	0.00	16	$y = 5.875 - 0.024x$
mean			3367				18 (2)	
(s.e.)			(1386)					

[a] General form of linear equation is: $y = a + bx$, where y is pine stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + bx$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (broadleaf cover * broadleaf modal height)/pine total height.

[c] General form of non-linear equation is $y = a e^{(b x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 142 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting hybrid spruce stem diameter from the competition indices, broadleaf density, broadleaf cover, and CRH, in the* Mixed Broadleaf-Shrub *Complex in the ICH zone*

Site	# of trees in the regression (n)	Conifer age (years)	Density threshold (stems/ha)	Linear regression equation predicting diameter from broadleaf density[a]	Adjusted r^2 for linear regression predicting diameter from broadleaf density[a]	p-value for linear regression predicting diameter from broadleaf density[a]	Cover threshold (%)	Linear regression equation predicting diameter from broadleaf cover[a]
5	70	13	2900	$y = 7.922 - 0.000x$	0.00	0.40	3	$y = 7.823 - 0.019x$
9	67	1	2000	$y = 3.440 - 0.000x$	0.12	0.02	3	$y = 3.666 - 0.033x$
39	72	13	2500	$y = 8.907 - 0.000x$	0.07	0.01	54	$y = 10.272 - 0.016x$
mean			2500				20 (17)	
(s.e.)			(260)					

[a] General form of linear equation is: $y = a + bx$, where y is spruce stem diameter, x is broadleaf cover or density, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + bx$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (broadleaf cover * broadleaf modal height)/spruce total height.

[c] General form of non-linear equation is: $y = a e^{(b x)}$, where y is spruce stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

TABLE 141 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover[a]	p-value for linear regression predicting diameter from broadleaf cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
0.20	0.00	15	$y = 4.428 - 0.021\,x$	0.32	0.00	$y = 4.451\, e^{(-0.006*x)}$	0.34
0.09	0.01	25	$y = 10.791 - 0.040\,x$	0.21	0.00		
0.05	0.04	5	$y = 5.799 - 0.015\,x$	0.09	0.01		
		15 (6)					

TABLE 142 *Continued*

Adjusted r^2 for linear regression predicting diameter from broadleaf cover[a]	p-value for linear regression predicting diameter from broadleaf cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
0.00	0.51	37	$y = 8.089 - 0.023\,x$	0.06	0.02	$y = 8.120\, e^{(-0.003*x)}$	0.07
0.31	0.00	0	$y = 3.534 - 0.006\,x$	0.36	0.00		
0.02	0.11	45	$y = 10.256 - 0.012\,x$	0.12	0.00		
		27 (14)					

The *Mixed Broadleaf-Shrub* Complex is widespread in the ICH and IDF zones of the southern interior, particularly on areas affected by logging and wildfire. The vast majority of sites dominated by broadleaves receive brushing treatments within a decade of planting, both to increase light availability to seedlings and to ensure that free-growing requirements are met (B.C. Ministry of Forests 1995a, 2000). A variety of brushing methods have been applied to this community, including manual cutting, girdling, cut stump–glyphosate, cut–spray glyphosate, foliar glyphosate spray, injection of broadleaves with glyphosate capsules, and basal application of triclopyr. Here we discuss fifth-year responses of Douglas-fir and vegetation to manual cutting, girdling, and cut stump–glyphosate treatment, and fifth-year responses of lodgepole pine and vegetation to manual cutting. These results focus on broadcast application of treatments because partial removal of broadleaf stems was uncommon at the time our studies were initiated.

Conifer Response

Survival

Survival of Douglas-fir and lodgepole pine seedlings growing amongst the *Mixed Broadleaf-Shrub* Complex was good to excellent (85–97%) during the 5-year measurement period, which we had anticipated because the majority of seedlings were well established (ranging in age from 3 to 17 years old) and healthy at the time of brushing. Seedling vigour generally improved in response to brushing, but survival was not increased any of the brushing treatments (manual cutting, girdling, cut stump–glyphosate). However, mortality from *Armillaria* root disease increased among Douglas-fir in the girdling treatment and among lodgepole pine in the manual cutting treatment in comparison with the controls. Eight percent of Douglas-fir in the girdling treatment died from *Armillaria*, compared with 3% of control seedlings. This translated into a significant difference in overall survival (90% in the girdling treatment versus 97% in the control) because *Armillaria* was virtually the only mortality agent. A greater proportion of lodge-pole pine also died from *Armillaria* root disease in the manual cutting treatment than in its control (9 versus 2% in year 5), but overall survival was not significantly affected because a greater proportion of control than treatment seedlings died from other causes (deer damage, weevils, and vegetation competition).

Greater incidence of *Armillaria* root disease following brushing has also been observed in other studies. For example, 3 years after manual and chemical brushing on a southern interior ICH site, Simard and Heineman (1996c) found 3–5% *Armillaria*-related mortality among Douglas-fir in control and chemical treatments and 15% in the cutting treatment. After 9 years, when seedlings were 13 years old, *Armillaria* had caused 20–23% mortality in the two brushing treatments, compared to 15% in the control. In another study, the incidence of *Armillaria* infection in 25-year-old ICH zone Douglas-fir plantations was twice as high on manually brushed as on unbrushed cutblocks (Woods 1994). Brushing the *Mixed Broadleaf-Shrub* Complex has not consistently increased the incidence of *Armillaria*-related seedling mortality, however. For instance, in our study, applying manual cutting and cut stump–glyphosate treatments in Douglas-fir plantations did not affect rates of mortality from *Armillaria* or overall seedling survival. Simard and Hannam (2000) likewise found that *Armillaria*-related mortality did not increase among spruce within 5 years of manual thinning or cut stump-glyphosate treatment (spruce were 13 years old at the time of assessment). Manual treatments may facilitate the spread of *Armillaria* root disease among conifers to a greater extent than chemical treatments (H. Merler, pers. comm., 2000). A possible explanation is that, although broadleaves are generally tolerant of *Armillaria*, the spread of the fungus through their root systems may be stimulated by treatments such as manual cutting, which stress but do not kill stems. Herbicide treatments, on the other hand, may induce chemical changes that make broadleaf roots less desirable hosts for the fungus. *Armillaria* can function as either a pathogen or a saprophyte; however, it is not a particularly competitive saprophyte, and is likely to be outcompeted by other, more aggressive species. Our results are compatible with this theory because increases in *Armillaria*-related mortality occurred in the manual cutting and girdling treatments, but not in the cut stump–glyphosate treatment. We did not find that mortality caused by *Armillaria* had increased among Douglas-fir following manual cutting, possibly because seedlings were relatively young and small during the assessment period.

There are several possible mechanisms by which brushing may increase the spread of *Armillaria* in brushed birch stands (Simard 1998). These are: (1) increased inoculum loads through the creation of dead, dying, or stressed birch stumps, (2) increased continuity of susceptible conifer inoculum, (3) higher probability of infection of remaining susceptible conifer stems, (4) increased growth rates of remaining susceptible trees, resulting in faster root-to-root contact, and (5) negative effect on the health of the below ground microbial community, reducing the stand's overall resistance to infection. For example, DeLong (1999) found that the *Armillaria*-antagonistic rhizosphere bacterium *Pseudomonas fluorescens* was significantly less abundant in pure Douglas-fir stands than in mixed stands with paper birch. In our study, manual cutting increased the incidence of mortality from *Armillaria* among lodgepole pine but not among Douglas-fir. Pine exhibited a more pronounced growth response following brushing than did Douglas-fir, which because of pine's larger stature, suggests that greater root-to-root contact may have contributed to increased spread of the root disease. The various brushing treatments in our study also differed in their effects on the incidence of *Armillaria*-related mortality among Douglas-fir seedlings. Girdling increased the proportion of Douglas-fir that died from the root disease, but manual cutting and cut stump–glyphosate treatment had no effect. This is possibly related to the greater age and size of Douglas-fir in the girdling treatment (10–22 years old at the fifth-year assessment), since root spread and root-to-root contact would presumably be greater in older conifers and provide a more continuous pathway for *Armillaria* to spread from dying broadleaves.

Further monitoring is required to evaluate the relationship between brushing treatments and the incidence of *Armillaria*-related conifer mortality. Rates of mortality due to *Armillaria* in our study ranged from 0.4 to 2.2%/yr, which is similar to rates of 1–2%/yr reported by Morrison et al. (1991) for 5- to 10-year-old Douglas-fir stands. According to Woods (1994), rates of infection are likely to be higher in the ICH than the IDF zone. There are insufficient long-term data to determine how *Armillaria* mortality rates change with stand age. However, the dynamics of the disease and infected stands suggest that rates may decrease once stands have outgrown the sapling stage (B. Van der Kamp, pers. comm., 1999).

Growth

Douglas-fir and lodgepole pine growth increased in response to all the brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex in our study, but they required more than a single year to do so. Stem diameter responded in advance of height, which is consistent with the literature (e.g., Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c). As of year 5, conifer height had increased only in response to the cut stump–glyphosate treatment.

Douglas-fir

Douglas-fir growing among the *Mixed Broadleaf–Shrub* Complex exhibited a larger growth response following the cut stump–glyphosate treatment than following girdling or manual cutting. In general, the magnitude of the growth response corresponded with efficacy of the brushing treatment at reducing broadleaf abundance, which is consistent with observations from several of our unreplicated treatments (Mather and Simard 1998a, 1998f, 1998k, 1998p; Appendix 1). Five years after cut stump–glyphosate application, Douglas-fir stem diameter, stem diameter increment, height, leader length, and height:diameter ratio had all improved. Stem diameter and height were 52 and 25% greater, respectively, among treated than control seedlings. The girdling treatment also improved growth of Douglas-fir, but more slowly and to a lesser degree than the cut stump–glyphosate treatment. This is likely related to the more advanced age of seedlings, and to the fact that girdling reduced broadleaf abundance gradually. After 5 years, Douglas-fir leaders were 56% longer in the girdling treatment and stem diameter was on the verge of responding (10.71 cm in the treatment versus 8.68 cm in the control, $p = 0.11$). A similar Douglas-fir growth response occurred as a result of manual cutting, where there was a 14% increase in stem diameter and a 29% increase in leader length, and no improvement in height:diameter ratio. Figures 156, 157, and 158 illustrate the extent to which the various treatments

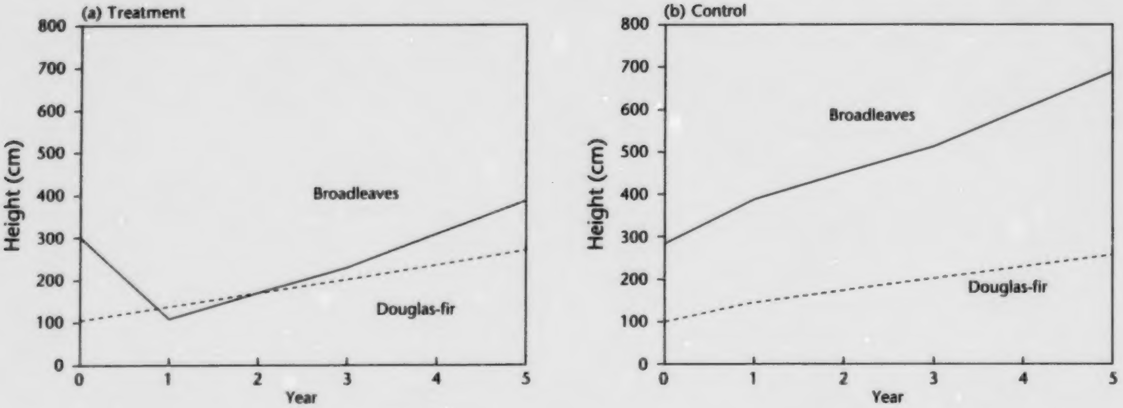

FIGURE 156 *Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH/IDF* Mixed Broadleaf-Shrub *Complex. Heights for years 2 and 4 were interpolated from actual data. Both treated and control Douglas-fir are expected to remain below the broadleaf canopy through the free-growing window.*

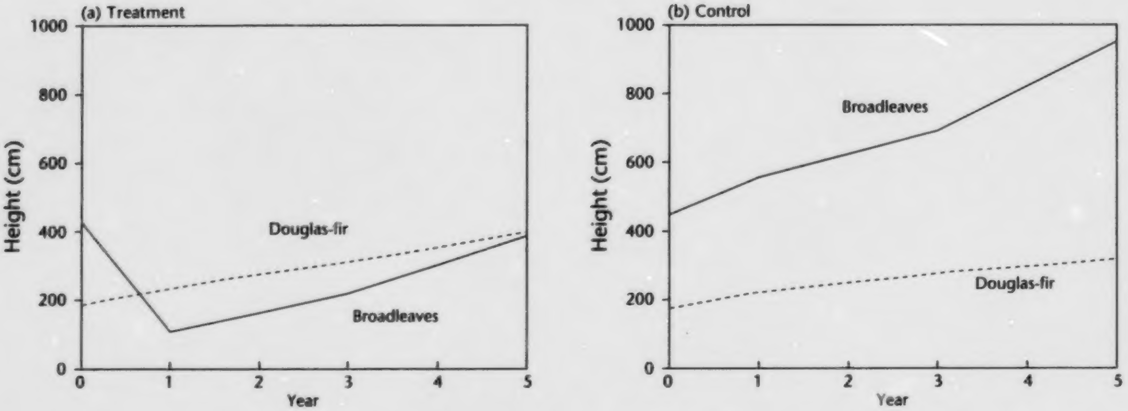

FIGURE 157 *Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following cut stump–glyphosate treatment in the ICH* Mixed Broadleaf-Shrub *Complex. Heights for years 2 and 4 were interpolated from actual data. Control Douglas-fir are expected to remain below the broadleaf canopy through the free-growing assessment period.*

reduced the height of broadleaves relative to Douglas-fir, and help explain the difference in seedling responses to the cut stump-glyphosate and manual treatments. Figure 158 is somewhat misleading regarding girdling, however, because it illustrates the average height of the few broadleaf stems missed by girdling and does not show that broadleaf cover was substantially reduced.

Simard and Heineman (1996a) also found that Douglas-fir growth increased following chemical, but not manual, treatments. In that study, manual cutting did not successfully reduce vegetation height below that of Douglas-fir, which may explain why seedlings did not respond to treatment. In comparison, broadcast glyphosate application reduced vegetation height well below that of conifers and resulted in a 31% increase in average stem diameter, but had no effect on height. Harper et al. (1998) studied the effects of multiple manual cutting treatments on an ICH *Mixed Broadleaf-Shrub* community, and found that average Douglas-fir stem diameter increased in response to treatment by

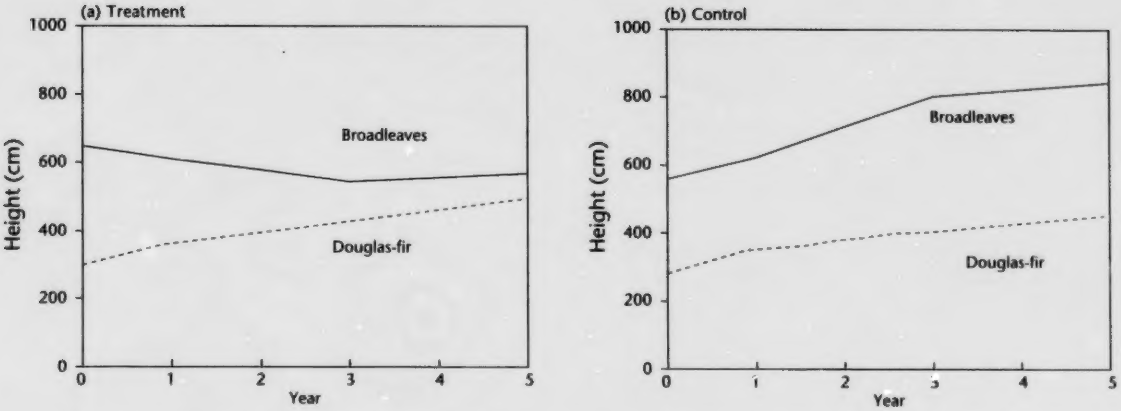

FIGURE 158 *Comparison of average Douglas-fir and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following girdling in the ICH* Mixed Broadleaf-Shrub Complex. *Heights for years 2 and 4 were interpolated from actual data. Control Douglas-fir will remain below the broadleaf canopy through the free-growing assessment period.*

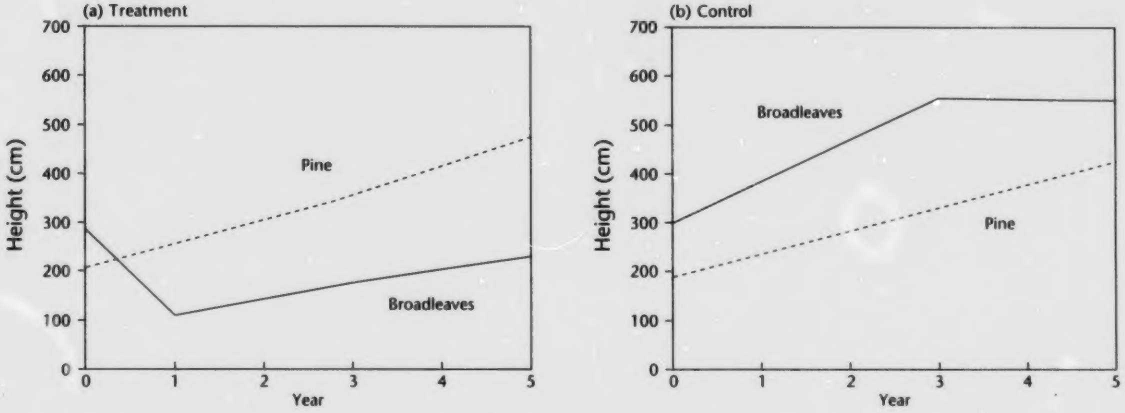

FIGURE 159 *Comparison of average lodgepole pine and broadleaf height profiles in (a) the brushing treatment and (b) the control in the years following manual cutting in the ICH* Mixed Broadleaf-Shrub Complex. *Heights for years 2 and 4 were interpolated from actual data. Treated broadleaves remained shorter than pine during the 5-year measurement period, and are expected to remain shorter through the free-growing assessment period.*

52–182% after 10 years, but differences between one, two, and three cutting passes were not significant. Cutting also improved stocking of Douglas-fir and reduced birch density. In yet another ICH study, average spruce diameter growth improved following cut stump-glyphosate and manual treatments that reduced birch abundance to 0 and 50 stems/ha, respectively, but not following a manual treatment that reduced birch density to 1000 stems/ha. None of the treatments affected average spruce leader length or total height within 5 years of treatment (Simard and Hannam 2000). These studies, as well as ours, indicate that brushing treatments that reduce birch density and height for sustained periods of time result in the largest conifer diameter responses, but that height responses do not always occur.

Both cut stump–glyphosate and girdling resulted in decreased height:diameter ratios among Douglas-fir in our study. Regardless, ratios in the controls were similar (slightly less than 60) to those reported by Cole and Newton (1987) in their least competitive treatment, and are not considered to reflect serious competitive stress. Cole and Newton's work took place in Oregon, where seedlings were only 5 years old, compared to a range of 8–22 years in our study.

Lodgepole pine

Stem diameter, diameter increment, and height:diameter ratio of lodgepole pine significantly increased within 3 years of manual cutting. There were no significant improvements in height by year 5, but the difference between treated and control trees was widening. Pine stem diameter was 37% greater in the treatment than in the control in year 5, which contributed to the difference in height:diameter ratio (56.0 in the treatment versus 68.5 in the control). Trees in the control were becoming increasingly spindly and their vigour was declining relative to those in the cutting treatment. Seedling growth responses following manual cutting were more pronounced among pine than Douglas-fir, probably because pine trees were able to maintain a height advantage over cut broadleaves (Figure 159), while Douglas-fir trees were overtaken within 2 years of cutting (Figure 156). In the northwestern interior ICH, young lodgepole pine growth exceeded that of several other conifer species when light levels were above 70% relative irradiance (Douglas-fir was not part of the study) (Coates and Burton 1999).

Plant Community Responses

Manual cutting

In both Douglas-fir and lodgepole pine plantations, manual cutting significantly reduced broadleaf abundance for at least 5 years. However, birch resprouted vigorously, and recovered to heights of 230 and 386 cm (approximately half the control heights) during that period. Nearly all cut stumps sprouted, and 67–85% of them still had an average of four to five sprouts after 5 years. Sprouts increased in height at average rates of 40–50 cm/yr during the measurement period, which was faster than Douglas-fir and approximately the same as lodgepole pine. The rapid recovery of the *Mixed Broadleaf-Shrub* Complex observed in our study corresponds with operational information summarized by others (Haeussler et al. 1990; Hart and Comeau 1992). Simard and Heineman (1996a) found that birch on a mesic ICH site sprouted even more vigorously, reaching heights of more than 2 m within 3 years of manual cutting. On a nearby site, birch sprouted far less vigorously, however, recovering to less than 1 m tall after 5 years (Simard and Hannam 2000). Peterson et al. (1997) suggest that birch sprouting can be minimized if manual cutting is applied in June through August, possibly because carbohydrate reserves are lower than during the dormant season (Haeussler et al. 1990). In our study, cutting took place on dates in July through October.

Manual cutting of the *Mixed Broadleaf-Shrub* Complex caused short-lived reductions in height of understorey shrubs, probably because some were cut at the same time as broadleaf stems. There were no effects on shrub cover or abundance of the herb layer, which is typical of our results for other complexes dominated by broadleaves or tall shrubs (i.e., *Aspen* Compex, *Wet Alder* Complex, *Dry Alder* Complex), and also similar to the results of Simard and Heineman (1996a). Cutting did not alter the richness or diversity of vascular species, which agrees with our findings for other complexes and with observations by Haeussler (1999).

Girdling

Girdling had a gradual effect on the *Mixed Broadleaf-Shrub* Complex because treated stems died slowly. The full impact of treatment was not expressed until year 3, whereas the manual cutting and cut stump–glyphosate treatments reduced vegetation abundance immediately. Girdling did not significantly reduce average height of broadleaves because scattered stems were missed. Reductions in cover were significant only in year 1 because of the large variability between sites, but, 5 years after girdling, broadleaf cover in the treatment was approximately one-quarter that of the control. In spite of the lack of statistical significance, we assume that the reductions in broadleaf abundance are responsible for increases in Douglas-fir growth.

Birch sprouted minimally following girdling; after 5 years, only 11% of girdled stems had sprouted, and there were only two sprouts per stem. However, those few sprouts grew at similar rates to sprouts in the manual cutting treatment. Our results contrast with reports that birch sprouts vigorously following girdling at breast height (Hart and Comeau

1992), but agree with others that girdling seriously damages or kills birch with minimal sprouting (Haeussler et al. 1990). Birch can apparently be girdled in any season for effective control (Hauessler et al. 1990); our broadleaves were girdled in August and mid-October.

Girdling broadleaf stems had no effect on shrub abundance, but herb cover increased briefly (in year 3 only). There were no differences in the richness of vascular species as a result of girdling, but species diversity was higher in the treatment than in the control in the first year after cutting. The difference did not persist, however, and may be related to variation in assessment date, or to different assessors collecting data from year to year.

Cut stump–glyphosate

The cut stump–glyphosate treatment had a larger and more lasting effect on the *Mixed Broadleaf-Shrub* Complex than either manual cutting or girdling. It reduced both cover and height of broadleaves for at least 5 years, and resulted in a larger growth response among Douglas-fir than the other two treatments. Five years after cut stump–glyphosate, broadleaf cover continued to be about one-quarter that of the control, and height about half. On average, about one-quarter of stumps sprouted following treatment, which was higher than we expected, and is due to poor chemical application at one site. Sprouts grew an average of 55 cm/yr during the monitoring period.

The cut stump-glyphosate treatment killed 72% of birch in our study, in spite of the missed stumps, which is similar to the 83% mortality reported by Simard and Hannam (2000). Biring et al. (1996) confirmed good control of birch with cut stump–glyphosate treatments that use 30–100% solutions. In our study, glyphosate was applied at full concentration rates of 0.74–3.20 kg ai/ha. We have unreplicated data for cut and spray glyphosate applications (birch sprouts are sprayed one season after manual cutting), foliar glyphosate application, and basal application of triclopyr. Preliminary results suggest that cut and spray is nearly as effective as cut stump-glyphosate (Mather and Simard 1998j; Appendix 1) and that foliar glyphosate spray also performs well (Mather and Simard 1998k; Appendix 1). Other sources also report that glyphosate spray has a severe effect on birch (e.g., Expert Committee on Weeds 1987; Biring et al. 1996); Simard and Heineman (1996a) found that birch height and cover were significantly reduced for at least 9 years by foliar glyphosate applied at 1.07 and 2.1 kg ai/ha. Biring et al. (1996) reported that basal triclopyr has a severe effect on birch, which is supported by results from our two triclopyr PROBE sites (unpublished data; Appendix 2).

Cut stump–glyphosate resulted in a modest decrease in shrub height 1 and 3 years after application in our study, possibly because of partial cutting of the shrub layer while broadleaves were being cut. There were no effects on shrub cover or abundance of the herb layer, and richness and diversity of vascular plant species associated with the *Mixed Broadleaf-Shrub* Complex were likewise unaffected. Boateng et al. (2000) found that spot application of glyphosate had no effect on structure or diversity of a boreal plant community; however, broadcast application reduced dominance of a tall shrub layer and increased structural diversity and richness of the herb layer. Sullivan et al. (1998) found that broadcast application of glyphosate had no effect on herbs, but it reduced the richness of shrub species. Both authors concluded that a single glyphosate application was unlikely to have an adverse effect on diversity of the vascular plant community. In our study, diversity of structural vegetation groups increased following the cut stump–glyphosate treatment because of the reduced dominance of broadleaves. This may have implications for wildlife species that are dependent on tall broadleaves for perching sites, nesting sites, or other habitat characteristics (e.g., Machmer and Steeger 1995).

Effects of the Community on Resource Availability

The *Mixed Broadleaf-Shrub* Complex occurs predominantly in the ICH zone, which includes some of the most productive ecosystems in southern interior British Columbia. Broadleaf trees and associated vegetation grow vigorously, and compete with conifers primarily for light rather than for soil water and nutrients. Simard (1990a) found that the best competition index for predicting Douglas-fir size in a paper birch-dominated community took into account the height of neighbouring vegetation and its distance from the target conifer, suggesting that light availability was paramount. Simard and Hannam (2000) likewise concluded that light availability was the main limitation to spruce growing among varying densities of birch. In that study, reducing the density of overtopping birch improved average spruce diameter growth, whereas reducing the density of understorey sprouts did not. Simard and Sachs (2001, in review) studied competitive processes in mixed birch-conifer stands in the southern interior ICH, and found that taller birch neighbours were the most important competitors with 11-year-old conifers, whereas shorter conifers and birch were the main competitors with 25- and 50-year-old conifers. Their results suggest that light competition was the most important determinant of conifer growth in young stands and that competition for soil resources increased as stands aged. Nevertheless, Simard and others noted that a plurality of competitive processes were likely operative in the mixed ICH stands they studied.

In our study, the largest conifer growth responses occurred following brushing treatments that reduced the height of broadleaves relative to conifers within a relatively short period of time (i.e., Douglas-fir response to cut stump–glyphosate and lodgepole pine response to manual cutting), which implies that competition was primarily for light. Wang, Simard and Kimmins (1995) showed that thinning 9- to 13-year-old paper birch from initial densities of 11 000–31 000 stems/ha to 400 or 1000 stems/ha increased photosynthetically active radiation under the canopy from less than 20% of full light to more than 80%. In another study, thinning 35-year-old birch to 600 stems/ha allowed approximately 45% of above-canopy radiation to reach newly planted white spruce, which the authors considered adequate for seedling growth (Comeau et al. 1998). In comparison with complete removal of birch, retention of at least 600 stems/ha also reduced height growth of sprouts in that study.

Although birch is a strong competitor for light, it also benefits conifer seedlings by increasing nutrient availability and contributing to the health and diversity of the rhizosphere. In the presence of birch roots, soil microbial populations are less likely to be nutritionally limited than in non-birch soils (Bradley and Fyles 1995). The diversity or richness of ectomycorrhizae on Douglas-fir roots has also been shown to increase in the presence of birch (Jones et al. 1997; Simard et al. 1997b). Ectomycorrhizae are well-known for their ability to enhance the uptake of water and nutrients (Kozlowski and Pallardy 1997), and they may also facilitate direct transfer of nutrients between two tree species (Simard, et al. 1997a). Birch accumulates high levels of nutrients within leaves and woody tissues (Wang et al. 1996) compared with neighbouring conifers (Simard 1995), which helps maintain ecosystem productivity when birch litter is cycled. A recent modelling study predicted eventual losses in overall stand productivity if birch were completely eliminated in favour of conifers (Sachs 1996). Nitrogen mineralization rates have been shown elsewhere to increase in the presence of birch, which has high levels of tissue nitrogen and relatively low levels of structural carbohydrates (Bradley and Fyles 1995; Evans et al. 1998). However, Prescott et al. (2000) recently found that birch foliage on ICH sites consistently decomposed more slowly than that of Douglas-fir, possible because of the higher tannin content, which implies that rates of nitrogen mineralization may slow in its presence. Thomas (1997) likewise found that nitrogen mineralization rates were slower under birch than under Douglas-fir.

Competition Thresholds

The competition thresholds for stem diameter of Douglas-fir, lodgepole pine, and interior spruce averaged 3664, 3367, and 2500 stems/ha for broadleaf density, 28, 18, and 20% for broadleaf cover, and 39, 15, and 27 for CRH, respectively. These thresholds apply to stands that are of free-growing age. Above the thresholds, interspecific competition appeared to be the most important factor limiting tree size, setting the upper limit for conifer stem diameter. A small proportion (19–39%) of conifers were growing in neighbourhoods above the thresholds, suggesting that competition was not constraining a portion of trees in the plantations. This was consistent among control as well as treated trees, indicating that many untreated conifers were naturally growing under low-moderate levels of broadleaf competition. Below the thresholds, stem diameter was highly variable among both treated and control trees; several trees (6–10%) were able to achieve greater growth (≥80% of the maximum diameter measured on the sites), but many appeared to be limited by other factors (e.g., microsite, genetics, and damaging agents such as root disease).

The regression analyses showed that the three broadleaf competition indices explained at best 43–46% of the variation in conifer stem diameter. The importance of competition in the *Mixed Broadleaf-Shrub* complex to conifer performance, as expressed by adjusted r^2 values, was moderately high compared to herbaceous and shrub complexes being evaluated with PROBE (this publication) as well as in other studies (e.g., Coates 1987; Simard 1989a; Wagner and Radosevich 1991). This is likely due to the closer equivalence in size and growth form of broadleaf neighbours to conifers (Goldberg and Werner 1983) as well as greater resource uptake by larger than by smaller neighbours (Harper 1977). In contrast, similar r^2 values have been reported in other studies relating individual conifer performance to competitive effects of paper birch or trembling aspen in 5–15-year old plantations (e.g., Simard 1990a; Morris and MacDonald 1991; Navratil and MacIsaac 1996; Newsome 1997, 1999; Simard 2001, in review). The generally moderate predictive ability of the regression models, the variable conifer performance at low and medium levels of competition, as well as the moderate portion of conifers constrained by detrimental broadleaf levels (i.e., above the thresholds), in combination suggest that performance of a portion of trees in the plantations will not improve predictably following broadcast brushing treatments. The regression and threshold results indicate that broadleaf competition was one of several factors affecting conifer growth in our operational plantations, and that alleviating competitive stress for a portion of trees will not alleviate the most important limitation to growth. Under variable stand and site conditions, competition is better viewed as one of many constraints rather than as a determinant of conifer performance (Burton 1993).

In spite of conifer performance variability within and between plantations, lodgepole pine and Douglas-fir increased in diameter by 14–52% following manual and/or cut stump–glyphosate treatments. Manual and chemical brushing treatments were successful at reducing broadleaf abundance below the cover and CRH thresholds for most suppressed conifers, resulting in their release. By contrast, considerably more Douglas-fir remained above broadleaf threshold densities 5 years following girdling, which may be attributed to spotty treatment, the older age of conifers at the time of treatment, and the slow death of girdled broadleaves. As a result, many suppressed trees were not released, and average Douglas-fir diameter still had not responded to girdling 5 years after treatment.

The variability in competition thresholds among sites was high in our study (coefficient of determination averaged 71% and was similar among conifer species and among broadleaf competition indices). This may reflect variability in stand history and conifer ages among our replicate sites; however, other studies have also found thresholds to vary considerably, even among similar sites (Simard 1990a; Burton 1993; Simard 2001, in review). Others acknowledge that management thresholds are necessarily variable because they are derived from a complex of factors and uncertainties (Cousens 1987), such as variable management objectives, ecosystems, stand compositions, stand ages, disease or insect problems, or administrative risks. As a result, calibration of thresholds on site-specific, target tree species–specific, and age-specific bases may be necessary for successful application of the threshold concept in developing management prescriptions in conifer-broadleaf mixtures.

The ranking of density thresholds among conifers in our study (Douglas-fir≅lodgepole pine>hybrid spruce) did not follow shade-tolerance patterns described by Krajina et al. (1982), who evaluated spruce as more shade tolerant than either lodgepole pine or Douglas-fir. However, hybrid spruce is more susceptible to moisture stress, and closes its stomata sooner than lodgepole pine (Binder et al. 1987). Therefore, under similar broadleaf densities, spruce may be more negatively affected than lodgepole pine by soil water competition, particularly on mesic and drier sites. In a recent study in the ICH zone, Coates and Burton (1999) found considerable variability and overlap in growth rates of lodgepole pine and hybrid spruce at moderate light levels (30–70% full sunlight), which probably encompass the light levels under the broadleaf thresholds identified in this study. The variability reflects the numerous factors other than light that affect conifer growth rates, such as soil water and nutrient availability, abiotic and biotic damage, and genetics. The lower thresholds identified for spruce than for pine or fir in this study may also have been a result of the low sample size for spruce. Notably, spruce thresholds were highly variable among sites, and standard errors generally overlapped those of the other two conifer species.

When broadleaf densities are very high, brushing may be more critical for the survival of lodgepole pine and Douglas-fir than of spruce. Kobe and Coates (1997) showed, for example, that 5-year survivorship of lodgepole pine (<10%) was considerably lower than of hybrid spruce (approximately 30%) at very low light levels (5% full sunlight). In our study, however, mortality did not vary among conifer species and little was due to broadleaf competition. Most mortality was caused by *Armillaria* root disease, and it increased following manual and girdling treatments. Our results suggest that broadleaf densities were too low to reduce light or soil water below compensation levels, and that other factors were primary agents of mortality. Growth of lodgepole pine and Douglas-fir may also benefit from dramatic reductions in broadleaves more so than growth of hybrid spruce. At high light levels (>70% full sunlight), Wright et al. (1998) and Coates and Burton (1999) showed that growth response of lodgepole pine was greater than that of hybrid spruce. Lodgepole pine is also more plastic than Douglas-fir in its growth response to increased light levels. In our study, there were too few replicates to evaluate average spruce response, but 5-year diameter response of lodgepole pine to manual cutting was considerably greater than that of Douglas-fir.

The broadleaf density threshold identified for Douglas-fir diameter in this study (3664 stems/ha) agrees with Simard (2001, in review), who found that 11-year-old Douglas-fir performance on mesic ICHmw sites declined dramatically above 4050 broadleaf stems/ha. The thresholds in these studies included broadleaves of all sizes. However, other studies in 9- to 13-year-old mixed broadleaf-conifer plantations have shown that taller broadleaves are the primary competitors with target conifers, and that shorter broadleaves have little additional competitive effect (Navratil and MacIsaac 1996; Simard and Sachs 2001, in review). Simard (2001, in review) found that inclusion of only those broadleaves taller than 11-year-old Douglas-fir resulted in a density threshold of 2575 taller broadleaf stems/ha.

Effectiveness of Treatment at Meeting Management Objectives

Common operational objectives of brushing the *Mixed Broadleaf-Shrub* Complex are to improve seedling growth by reducing competition from broadleaves, and to assist in meeting free-growing requirements (B.C. Ministry of Forests 1995a, 2000). The *Mixed Broadleaf-Shrub* Complex tends to be brushed after conifers are well-established, so that improving seedling survival is not a common objective, although there is some concern that mortality will increase with development of these stands if they are left untreated (B. Fraser, pers. comm. 2001). The extent to which free-growing and growth goals were met for Douglas-fir increased with the extent to which brushing reduced broadleaf abundance, even though other ecosystem effects are poorly understood. Objectives were met more easily for lodgepole pine than for Douglas-fir because of larger initial seedling size and a faster growth rate.

For our ICH sites, the old (1995) free-growing guidelines specified target stocking of 1200 (minimum 700) well-spaced conifers/ha, and required that 9–15 years after harvest (12–15 years on some sites), that Douglas-fir and lodgepole pine must be at least 1.4 and 2.0 m tall, respectively, and that both species must be 150% as tall as the surrounding vegetation. For our IDF sites, the old guidelines specified target stocking of 1000 (minumum 500) well-spaced conifers/ha, and required that 12–15 years after harvest, Douglas-fir must be at least 0.8 m tall and 125% as tall as surrounding vegetation. The new (2000) guidelines allow retention of specific densities of broadleaves that exceed the height of conifers in one of four quadrants in the free-growing assessment radius. For our sites, the new guidelines allow retention of 600 broadleaf stems/ha in Douglas-fir plantations and 400 stems/ha in lodgepole pine plantations. We have not yet surveyed according to the new guidelines, but fifth-year survey information collected according to the old guidelines showed there were significantly more free-growing trees in the treatment than the control in all the treatment cells. Our survival and growth results suggest that stocking and minimum height requirements were met (on average) in both the treatments and controls of all four treatment cells, and that Douglas-fir in the cut stump treatment (Figure 157) and pine in the manual cutting treatment (Figure 159) were likely to meet the conifer:vegetation height ratio requirement, on average, at the early free-growing assessment age. Girdling left some tall broadleaves (Figure 158), but competitive status data suggest that at least three-quarters of Douglas-fir were no longer overtopped in that treatment. Data collected according to the old free-growing guidelines indicates that although there were more free-growing trees/ha in the girdling treatment than the control (370 versus 166 stems/ha), the majority remained overtopped to some extent. Results may be different when surveys are conducted under the new guidelines. According to our height data, manual cutting is unlikely to help Douglas-fir meet the conifer:vegetation height ratio requirement (on average) because seedlings were quickly overtaken by broadleaf sprouts (Figure 156). However, silviculture survey data collected according to the old guidelines suggests there were approximately 185 more free-growing trees/ha in the cutting treatment than the control (502 versus 315 stems/ha). Future assessment using the new guidelines will provide more current information. Simard and Heineman (1996a) likewise found that manual cutting did not allow Douglas-fir to grow above the *Mixed Broadleaf-Shrub* Complex, but that foliar glyphosate reduced broadleaf height well below that of seedlings. Simard and Hannam (2000) found that a cut stump–glyphosate treatment allowed spruce to meet the conifer:vegetation height ratio, whereas cutting was ineffective because birch sprouted so vigorously. In our study, control broadleaves were taller than conifers and far exceeded threshold densities throughout the 5-year monitoring period. None of the control stands we studied are expected to meet free-growing requirements under the new guidelines (B.C. Ministry of Forests 2000).

It did not appear necessary to improve survival in our study because conifers were well established and healthy at the time of treatment. To the contrary, manual cutting and girdling resulted in an increase in *Armillaria*-related mortality among lodgepole pine and Douglas-fir, respectively. This has increased disease incidence from moderate to high (B.C. Ministry of Forests 1995a). Further mortality may yet occur, since other studies (e.g., Morrison et al. 1991; Woods 1994; Simard and Heineman 1996a) suggest that our stands are too young for the disease to be fully expressed. Douglas-fir growth was most improved by the cut stump–glyphosate treatment, which was associated with the greatest reductions in broadleaf abundance compared with other treatments. In comparison, faster-growing lodgepole pine responded well to manual cutting, probably because they were able to keep ahead of sprouts. Longer-term monitoring is required to determine whether growth responses affect yield or rotation length and to monitor the interaction between brushing and *Armillaria* root disease.

In summary, the management objectives of improving juvenile conifer growth and creating free-growing stands were most successfully met in the *Mixed Broadleaf-Shrub* Complex following brushing treatments that severely set back the broadleaves (i.e., chemical treatments). However, such treatments are likely to reduce the presence of broadleaves in seral conifer-dominated stands at maturity (Simard and Sachs [2001, in review]). Many studies have shown that birch has beneficial effects on biodiversity, forest productivity, and forest health (e.g., Sachs 1996; Wang, Simard, and Kimmins 1995; Gerlach et al. 1997; Jones et al. 1997; Peterson et al. 1997; Simard et al. 1997b; DeLong 1999). Our threshold results, as well as those of Simard (2001, in review), indicate that young conifers perform well in the company of 2500–4000 total birch stems/ha, of which Simard suggests 700–3300 stems/ha can be taller than the conifers, depending on the shade tolerance of the species. The new free-growing guidelines acknowledge the benefits of broadleaves by allowing retention of certain densities of broadleaves (B.C. Ministry of Forests 2000). Birch distribution in the *Mixed Broadleaf-Shrub* Complex is typically patchy, so that some conifers are overtopped in dense patches, others are partially encroached upon, and still others are open-grown. With increased understanding of competitive mechanisms and competitive thresholds, Simard (2001, in review) and Simard and Sachs (2001, in review) suggest that brushing of young conifer plantations may be tailored to relieve competition for light to only those trees that need it.

Brushing the *Mixed Broadleaf-Shrub* Complex significantly improved conifer growth in our study, and the largest seedling growth responses occurred where broadleaf abundance was most reduced. However, brushing was not needed to improve survival because conifers were well established at the time of treatment. To the contrary, our results indicate that rates of mortality from *Armillaria* root disease increased following manual cutting or girdling of broadleaves. Without brushing, stands typically cannot meet all the free-growing requirements (B.C. Ministry of Forests 2000) within the assessment window, and the treatment that most reduced broadleaf abundance (cut stump–glyphosate) was most successful at improving their status. However, many studies have shown that the presence of some broadleaf trees is beneficial to conifers, and our competition thresholds suggest that, depending on species, conifers can be successfully grown with a broadleaf component of approximately 2500–4000 total stems/ha.

MANAGEMENT IMPLICATIONS

1. Brushing the *Mixed Broadleaf-Shrub* Complex is not required to ensure good conifer survival, as long as seedlings are well established at the time of treatment. *Armillaria*-related mortality of lodgepole pine and Douglas-fir seedlings actually increased in manually cut and girdled stands, respectively, compared to untreated stands. In contrast, *Armillaria*-related mortality was unaffected by chemical treatments, which agrees with other studies in the southern interior. Further research is required before recommendations can be made regarding brushing in *Armillaria*-infested stands. A prudent approach to minimizing mortality in these stands would be to avoid brushing these stands altogether if conifers are growing adequately, or to brush only around suppressed conifers using localized chemical application.
2. Conifer diameter growth can be improved by brushing the *Mixed Broadleaf-Shrub* Complex. Height growth responses lag behind diameter responses, and other studies indicate that they generally do not appear until at least 5 years after brushing. Except for the increase in *Armillaria*-related mortality, brushing has tended to improve seedling vigour. However, there are currently no data to indicate whether short-term growth responses will affect stand yield over the long term.
3. Broadleaf thresholds for Douglas-fir, lodgepole pine, and interior spruce stem diameter averaged 3664, 3367, and 2500 stems/ha, 28, 18, and 20% broadleaf cover, and 39, 15, and 27 CRH, respectively. Reducing broadleaf abundance to the thresholds should improve stem diameter, but further reductions will not necessarily affect growth predictably. Broadleaves of all sizes were used in the threshold estimates.
4. Our results suggest that manual cutting will allow lodgepole pine to meet the conifer:vegetation height ratio free-growing requirement, but that Douglas-fir are too slow-growing to keep ahead of birch sprouts. Cut stump–glyphosate and girdling treatments show more promise for allowing Douglas-fir to attain free-growing status. Brushing does not improve the ability to meet stocking or minimum height requirements for free-growing, and increases in *Armillaria* mortality may eventually reduce stocking in brushed stands. In our study, untreated stands occupied by the *Mixed Broadleaf-Shrub* Complex are unlikely to meet the conifer:vegetation height ratio or density requirements for free-growing under the new guidelines (B.C. Ministry of Forests 2000).
5. A possible alternative to broadcast brushing of the *Mixed Broadleaf-Shrub* Complex is selective brushing of only competition-stressed conifers. In another study in stands of free-growing age, Simard (2001, in review) suggests that broadleaves taller than conifers be removed down to thresholds of 3325, 2575, and 733 stems/ha for western redcedar, Douglas-fir, and western larch, respectively.

SECTION 12

OVERALL SUMMARY

This section ideally should be read as a summary to the preceding sections for individual vegetation complexes, but given the length and scope of the document, we recognize that it may be read independently. It is important, however, that the summary be read in the context of our study, keeping in mind its objectives and limitations, as they are described below.

The PROBE program investigated the effects of operational brushing treatments on conifer performance and plant community condition in the southern interior of British Columbia with the overall goal of advancing our ability to assess, predict and treat vegetation competition problems in young conifer stands. The general objectives of our study were:

1. to quantify the effects of operational brushing treatments on conifer seedling survival, growth, health, and free-growing status;
2. to quantify the effects of operational brushing treatments on the abundance, structure, diversity, and condition of the plant communities;
3. to identify competition thresholds for conifer growth;
4. to discuss possible effects of operational brushing treatments on various ecosystem attributes; and
5. to assess whether brushing treatments were meeting biological and management objectives.

STUDY SCOPE

The PROBE program was designed to test the effects of operational brushing on conifer crop tree performance and plant community condition across a broad array of vegetation complexes and brushing treatments in the southern interior of British Columbia. The experimental design, which used replicated, randomized, and paired control and brushing treatment plots, allowed standard parametric statistical analyses to test the effects of "brushing" versus "doing nothing." The experimental design provided an effective tool to realistically evaluate impacts of operational brushing on conifer performance and plant communities. PROBE differs in design and approach with many vegetation management research experiments, which helps explain why we *sometimes found* less dramatic effects of brushing. These include: (1) we evaluated variable and moderate vegetation problems characteristic of operational brushing projects rather than the highly brushy conditions often evaluated in many research studies; (2) we measured average responses rather than potential responses; and (3) we replicated our studies across variable sites rather than a single or few similar sites. The replication of operational treatments in PROBE across variable site conditions provides broader scope of inference of the results than most research studies, but also results in limitations in its power to detect small treatment effects.

STUDY LIMITATIONS

Application of the results of this study is limited to the operational conditions that were examined. These conditions must be carefully considered when relating the results to silviculture practices.

1. The brushing treatments and plant communities we studied were common components of operational brushing programs in the Kamloops and Nelson forest regions. They were studied because of the high frequency with which the plant communities were targeted, and brushing treatments were applied by southern interior licensees and forest districts. We were not able to study all treatments that are commonly applied in the southern interior because there were limitations in the availability of candidate sites as well as the availability of funding. Most treatments that were chosen for study in the early to mid-1990s were still commonly applied in 1998, as shown in provincial summaries of brushing activities (Figures 1 and 2). However, practices apparently have changed in some areas of the southern interior since PROBE was initiated, including faster application of brushing following planting as well as more frequent application of multiple rather than single manual treatments. Because of the time required for treatment responses to occur and be evaluated, and the shortage of funding available to track treatment changes, there necessarily is a lag between some of these recent operational treatments and those evaluated and reported here.
2. Our study was limited to circum-mesic sites. There were two interrelated reasons for this limitation. Limitations in funding necessitated that we narrow the scope of our study, and we focused on circum-mesic conditions because they were most widely applicable to operations. In addition, circum-mesic sites were the most frequently brushed sites in the southern interior, and were therefore the most frequently available for study. Terrestrial ecosystem mapping projects show that circum-mesic sites comprise approximately 75% of the forested landbase, and an even larger proportion of the logged and brushed landbase (D. Lloyd, pers. comm. 2000). Because of this limitation, this study may not have detected potential vegetation problems on highly specific sites (e.g., subhygric sites). Similarly, we may not have detected problems at certain ages (e.g., 1–2 years old) because most brushing treatments are operationally applied several years post-treatment, when competitive conditions are apparent.
3. Brushing treatments were not always applied in exactly the same way to each replicate site in a particular treatment cell. Therefore, our interpretations are made of general treatment methodology (e.g., manual versus chemical, broadcast versus tree-centred) rather than specific treatment attributes (e.g., specific times or rates of application). Care must be taken not to extrapolate our results to treatments or complexes that were not measured in our study, just as our results should not be extrapolated to other regions of the province.
4. We have measured brushing responses for five years in most cases (9 out of 15 treatments), and only three years for four treatments and one year for two treatments (Table 143). Care must be taken in extrapolating the results of this study beyond the measurement years. It is possible that brushing responses may appear, disappear, magnify, or diminish as time since treatment increases. Additionally, competitive interactions are expected to change with time, and the results presented here apply only to the plantation age range operationally treated and measured (see Table 143).
5. The objective of our study was to evaluate brushing treatments rather than to evaluate the more complex silviculture treatment regime (harvest, site preparation, planting) that led to the treatable vegetation condition. The competitive status of seedlings and the need for brushing was determined by the silviculturist prescribing treatment for the site, and our study set out to test the assumptions made about competition and to measure the average responses to the operational prescriptions. Evaluating the silviculture regime that led to the competitive condition being treated was beyond the stated scope of this study, and was not feasible given the level of funding committed to the program. Nevertheless, we recognize that different harvesting, site preparation, and planting regimes can affect the competitive status of plantations. We have tried to address this variance by restricting our replicate

TABLE 143 *Summary of conifer responses*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Pre-treatment vegetation characteristics			Seedling survival response[b]	Seedling growth response[b]	Remarks about vegetation responses	Will treatment help meet free-growing?	Remarks about free-growing
					Vegetation component	Cover (%)	Height (cm)					
Herb and low-elevation complexes												
Fireweed	ESSF/ ICH	Se 2–4 years	Manual	3	Fireweed	45	110	NO	NO	• Vegetation competition was not severe enough to cause mortality or growth losses to seedlings (average survival across the treatment and control was 96% after 3 years) or cause large reductions in growth. • Vegetation recovered rapidly from a single manual cutting treatment.	NO	• Vegetation competition did not reduce stocking. • Seedlings outgrew this complex without brushing. • Brushing is not predicted to decrease the time required to meet free-growing.
					All vegetation	76	95					
					Herbs	66	96					
					Shrubs	16	62					
Fireweed	ICH/ ESSF	Pl 1-3 years	Manual	5	Fireweed	45	90	NO	NO	• As above (average survival across the treatment and control was 88% after 5 years)	NO	• As above
					All vegetation	76	85					
					Herbs	64	79					
					Shrubs	17	52					
Fireweed	ESSF/ ICH	Se 1-5 years	Glyphosate	5	Fireweed	53	105	NO	YES(+)	• Vegetation competition was not severe enough to cause seedling mortality (average survival across the treatment and control was 91% after 5 years). • Reduced vegetation abundance resulted in minor or temporary growth improvements (e.g., a short-lived increase in stem diameter that disappeared by year 5 and reduced H:D ratio)	NO	• As above
					All vegetation	82	88					
					Herbs	76	88					
					Shrubs	13	65					
Fireweed	ESSF	Se 0–5 years	Grazing	1	Fireweed	29	93	NO	NO	• Vegetation competition was not severe enough to cause seedling mortality or growth losses (average survival across the treatment and control was 94% in year 1). • Vegetation recovered rapidly from a single grazing treatment.	NO	• As above
					All vegetation	82	79					
					Herbs	68	74					
					Shrubs	19	94					

TABLE 143 *Continued*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Pre-treatment vegetation characteristics Vegetation component	 Cover (%)	 Height (cm)	Seedling survival response[b]	Seedling growth response[b]	Remarks about vegetation responses	Will treatment help meet free-growing?	Remarks about free-growing
Fern	ICH	Sx 2–4 years	Glyphosate	5	Lady fern Thimbleberry All vegetation Herbs Shrubs	28 13 86 64 30	79 57 99 90 94	NO	YES(+)	• Vegetation competition was not severe enough to cause seedling mortality or or growth losses (average survival across the treatment and control was 93% after 5 years). On one site, brushing was applied after extensive mortality had already occurred. • Reduced vegetation abundance caused significant improvements in stem diameter, stem diameter increment, height, leader length, and H:D ratio.	NO	• We predict minimum height and conifer:vegetation height ratio requirements will be met without brushing. • Treated seedlings grew above vegetation 2 years ahead of control seedlings • Stocking could have been improved by earlier brushing on at least one of the sites.
Mixed Shrub	ICH/ ESSF	Sx 1 year	Manual	3	All vegetation Shrubs Herbs	81 44 51	85 78 81	NO	YES(+)	• Vegetation-related mortality was high in both the treatment and control (average survival across the treatment and control was 75% in year 3) because vegetation recovered rapidly following manual cutting. • Stem diameter and H:D ratio improved among surviving seedlings as a result of manual cutting.	NO	• Stocking requirements are likely to be met if there is little future mortality. • Surviving seedlings are likely to meet minimum height and conifer:vegetation height ratio requirements without brushing. • Treated seedlings are predicted to be as tall as surrounding vegetation only 1 year ahead of control seedlings.

TABLE 143 *Continued*

					Pre-treatment vegetation characteristics							
Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Cover (%)	Height (cm)	Seedling survival response[b]	Seedling growth response[b]	Remarks about vegetation responses	Will treatment help meet free-growing?	Remarks about free-growing
Mixed Shrub	ICH/ ESSF	Sx 1–2 years	Sheep grazing	1	Fireweed	26	82	NO	NO	• Grazing reduced fireweed height and cover for one year, but this had no effect on first-year seedling survival (average 94% across the treatment and control) or growth.	NO	• Minimum height and conifer:vegetation height ratio requirements are likely to be met without brushing. • There is potential for future mortality among these young seedlings, which are declining in vigour. This could affect stocking requirements.
					All vegetation	89	86					
					Shrubs	51	91					
					Herbs	46	71					
High-elevation shrub complexes												
Ericaceous Shrub	ESSF	Se 0–2 years	Manual	5	All vegetation	88	113	YES(+)	YES(+)	• Seedling survival was significantly higher in the manual cutting treatment (89%) than in the control (71%) in year 5. • Minor growth improvements (longer leaders, lower H:D ratio) also resulted from manual brushing.	YES	• Brushing will help meet the stocking requirement. • Brushed seedlings are likely to meet the conifer conifer:vegetation height ratio requirement 4 years ahead of control seedlings.
					Shrubs	58	117					
					Herbs	45	48					
Tall shrub complexes												
Dry Alder	MS	Pl 5 years	Manual	5	Alder	22	192	NO	NO	• Vegetation competition had no effect on survival (average survival across the treatment and control was 93% in year 5) or growth of pine seedlings.	NO	• Seedlings in both the control and treatment were taller than the *Dry Alder* Complex by year three (age 8). • Brushing is not necessary to meet any of the free-growing requirements.
					Shrubs	48	170					
					Herbs	34	71					

TABLE 143 *Continued*

					Pre-treatment vegetation characteristics							
Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Cover (%)	Height (cm)	Seedling survival response[b]	Seedling growth response[b]	Remarks about vegetation responses	Will treatment help meet free-growing?	Remarks about free-growing
Wet Alder	ESSF	Se 4–6 years	Manual	3	Alder	32	258	NO	YES(+)	• Most seedling mortality had occurred prior to the cutting treatment. • Manual cutting had no effect on survival of the established seedlings (average survival across the treatment and control was 93% in year 3). • H:D ratio is **slightly** lower in the brushing treatment after 3 years.	YES & NO	• Brushing will help meet the minimum height and conifer:vegetation height ratio requirements. • Stocking could be reduced below minimum standards because of mortality that occurred prior to brushing and because of accidental cutting. • A second cutting will likely be necessary to meet conifer:vegetation height ratio requirements.
					Shrubs	55	234					
					Herbs	44	87					
Broadleaf complexes												
Aspen	IDF/ MS	Pl 7–10 years	Manual	3	Aspen	26	326	NO	YES(+)	• Brushing was not needed to ensure excellent survival (100% in both the treatment and control after 3 years). • H:D ratio and stem diameter improved **slightly** following manual cutting.	YES	• Reductions in broadleaf height and cover were not statistically significant; however, they were likely sufficient to allow pine to outgrow surrounding vegetation.
					Shrubs	25	116					
					Herbs	59	29					
Mixed Broadleaf-Shrub	ICH	Fd 5–6 years	Manual	5	Broadleaves	16	291	YES(-)	YES(+)	• Brushing **reduced** third-year survival because of increased *Armillaria*-related mortality. • Brushing had no effect on survival by year 5 (average across the treatment and control was 88%). • Brushing improved vigour of surviving seedlings and resulted in larger stem diameters and longer leaders after 5 years.	YES	• Brushing was necessary to meet the conifer:vegetation height ratio requirement.
					Shrubs	35	87					
					Herbs	23	67					

TABLE 143 *Concluded*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Pre-treatment vegetation characteristics			Seedling survival response[b]	Seedling growth response[b]	Remarks about vegetation responses	Will treatment help meet free-growing?	Remarks about free-growing
					Vegetation component	Cover (%)	Height (cm)					
Mixed Broadleaf-Shrub	ICH	Pl 3–10 years	Manual	5	Broadleaves Shrubs Herbs	16 40 26	293 95 64	YES(-)	YES(+)	• Manual cutting caused an increase in *Armillaria*-related mortality of pine in year 3. • Cutting improved vigour of surviving seedlings and resulted in larger stem diameter and stem diameter increment and lower H:D ratio after 5 years.	YES & NO	• Brushing was necessary to meet the conifer:vegetation height ratio requirement. • Our data suggest manual cutting may increase the spread of *Armillaria*, which could affect stocking.
Mixed Broadleaf-Shrub	ICH	Fd 8–9 years	Cut stump–glyphosate	5	Broadleaves Shrubs Herbs	54 46 30	438 85 65	NO	YES(+)	• Cut stump–glyphosate had no effect on Douglas-fir survival (average across the treatment and control was 95% in year 5). • Cut stump–glyphosate resulted in relatively large improvements in seedling stem diamter, stem diameter increment, height, and H:D ratio.	YES	• Brushing was necessary to meet the conifer:vegetation height ratio requirement. • Other studies suggest chemical treatments may be less likely to stimulate the spread of *Armillaria* than manual treatments.
Mixed Broadleaf-Shrub	ICH	Fd 5–17 years	Girdle	5	Broadleaves Shrubs Herbs	25 29 34	604 110 94	YES(-)	YES(+)	• Girdling **reduced** survival in year 5 (90% in the treatment vs. 97% in the control), mainly as a result of of increased *Armillaria*-related mortality. • Girdling resulted in a **minor** increase in leader length after 5 years. Seedlings may be responding slowly to girdling because treated broadleaves died gradually.	YES & NO	• Brushing was necessary to meet the conifer:vegetation height ratio requirement. • Our data suggest manual cutting may increase the spread of *Armillaria*, which could affect stocking.

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[a] Age (years since planting) at the time of brushing.
[b] NO indicates no significant treatment response, YES(+) indicates a significant positive treatment effect, and YES(-) indicates a significant negative treatment effect.

sites to those that were clearcut, site prepared (in most cases), and planted with specific tree species. We have also considered, in our management recommendations, site preparation and planting treatments that may result in lowered competitive conditions and reduced need for brushing. There is, however, a need to expand silviculture treatment evaluations to include a regime of treatments rather than brushing alone.

6. Our evaluation of brushing effects on plant communities was limited by the methodology used. For example, particular tree and plant species were chosen for measurement when PROBE sites were established, and changes in other species as a result of brushing (e.g., species shifts) would therefore not have been detected. In addition, we used conventional measures of plant species diversity in our analysis (i.e., Shannon-Weaver and Simpson Diversity Indices), and these measures are limited in their ability to detect changes to particular properties of diversity as well as in their relationship to ecological function (Hurlbert 1971).

Conifer survival was improved in only one of the fifteen operational brushing treatment cells examined in this study (Table 143). We offer several possible explanations for this survival response:

1. Vegetation competition was, on average, not intense enough to threaten overall conifer survival in many of the vegetation complexes studied. We found examples of this phenomenon on circum-mesic sites in the *Fireweed, Dry Alder, Mixed Broadleaf-Shrub,* and *Aspen* complexes. In these complexes, survival in the untreated controls was consistently >85%. Plant communities were well developed on these sites, but we found that agents other than vegetation competition appeared to have contributed to most of the mortality (e.g., disease, rodents, microclimate), except in localized, dense vegetation patches. Many other studies have shown that vegetation competition in operational plantations is commonly not intense enough to cause mortality of established conifers, even though it can cause growth losses (Wagner et al. 1989; Wagner and Radosevich 1998; Simard, Heineman, and Youwe 1998). Competition-related mortality has been observed to occur during the lag between planting and brushing, in the wetter subzones of the ICH, and over long time periods, but this was not evaluated in our study because of limitations in treatment method and timing that were operationally applied, the candidate sites that were available for study, the period of time that had lapsed since treatment application, and the funding that was available to establish new trials.
2. In our studies of the *Dry Alder, Mixed Broadleaf-Shrub* and *Aspen* complexes, plantations were generally adequately stocked with well-established conifers at the time of brushing. We found that brushing had no effect on conifer survival in these complexes, which agrees with most other brushing studies in British Columbia (Comeau et al. 2000b).
3. In some cases, brushing may have been applied too late to have an effect on seedling survival. This applies to some of the moister sites in the *Fern, Fireweed,* and *Mixed Shrub* complexes, where silviculture survey information and history records suggest that vegetation-dependent mortality occurred soon after plantation establishment.

   To improve survival and stocking on moist to wet sites, or on mesic sites in wetter subzones, observations suggest that brushing should be applied within 1–2 years of planting, before competition intensifies.
4. The single manual cutting and grazing treatments that were commonly applied to dense herb and shrub patches in the *Fireweed* and *Mixed Shrub* Complexes were ineffective at improving conditions for early survival. Vegetation usually rebounded to pre-treatment levels within one growing season, which was too soon to reduce seedling mortality. Other studies suggest that brushing treatments that result in sustained vegetation suppression, such as glyphosate or multiple manual and grazing applications, are necessary if survival is to be improved. Foliar glyphosate application is the most cost-efficient treatment, but multiple manual or grazing treatments can be equally effective where there are site or social constraints to the use of herbicides.
5. Subhygric sites, where the *Fireweed, Fern* and *Mixed Shrub* complexes tend to be most vigorous, were not generally evaluated. Instead, the PROBE program focused on evaluating circum-mesic sites because that is where most operational brushing occurred. Subhygric areas where vegetation is dense are often small patches embedded within a mesic matrix, and are difficult to assess using the large PROBE plots.
6. There was one complex in which conifer survival was improved by brushing. Survival of Engelmann spruce seedlings was substantially improved following selective, tree-centred manual cutting in the well-developed *Ericaceous Shrub* Complex. Seedlings were very young (≤2 years old) at the time of brushing and had not yet suffered substantial vigour losses. Consequently, small reductions in the slowly growing ericaceous shrubs, mainly rhododendron and false azalea, were sufficient to reduce early seedling mortality.

Some brushing treatments applied in the *Mixed Broadleaf-Shrub* Complex reduced survival because of significantly increased mortality due to *Armillaria* root disease. Five-year mortality among lodgepole pine was 4.5 times greater where neighbouring broadleaves were manually cut (9%) compared to where they were left untreated (2%).

Similarly, 5-year mortality of Douglas-fir increased from 3% to 8% following broadleaf girdling. Greater incidence of *Armillaria* following brushing has been observed in other studies as well (Woods 1994; Simard and Heineman 1996a), and has been attributed to increased disease inoculum loads and increased rates of conifer root growth and inoculum contact. In contrast to girdling, manual cutting and cut stump–glyphosate treatments had no effect on Douglas-fir survival. In the manual cutting treatment, Douglas-fir and the broadleaves were younger and smaller than in the other girdling and cutting treatments, and therefore the rate of contact with *Armillaria* inoculum may have been slower and inoculum potential may have been lower. In the cut stump–glyphosate treatment, the chemical may have slowed the spread of *Armillaria* root disease by killing roots faster and increasing their attractiveness to more competitive saprophytes.

Longer-term measurements are required to quantify changes in *Armillaria* mortality rates as inoculum potential decreases with stand age, and therefore to determine the importance of treatment-related mortality to stand performance. At present, we suggest that caution be exercised in prescribing brushing for young conifers growing among the *Mixed Broadleaf-Shrub* Complex on infected sites to ensure that resultant mortality does not outweigh growth benefits. Where conifer performance is substantially compromised by vegetation competition, our results suggest that *Armillaria*-caused mortality may be reduced by applying chemical rather than manual treatments. To minimize inoculum loads on these sites, we suggest that treatments be applied selectively to release stressed individuals only, rather than using a broadcast approach. Our suggestions support the *Root Disease Management Guidebook* of the Forest Practices Code (B.C. Ministry of Forests 1995c), which indicates that brushing be restricted where *Armillaria* root disease incidence reaches the levels measured in our study.

Conifer diameter increased on average following ground-foliar glyphosate treatment in the *Fern* Complex, manual cutting in the *Mixed Shrub* Complex, and manual cutting and cut stump–glyphosate treatments in the *Mixed Broadleaf-Shrub* Complex (Table 143). Average diameter of 2- to 4-year-old hybrid spruce increased by 58% (1.5 cm) 5 years after foliar glyphosate treatment of the *Fern* Complex. By contrast, glyphosate application had no significant effect on 5-year diameter of spruce growing in the less competitive *Fireweed* Complex, but it did reduce height:diameter ratio. Manual cutting resulted in a smaller response among newly planted to 3-year-old spruce growing in the *Mixed Shrub* Complex, where average diameter increased by 23% (0.3 cm) 3 years after treatment. Five to 9-year-old Douglas-fir growing in the *Mixed Broadleaf-Shrub* Complex exhibited 5-year diameter increases ranging between 14% (0.6 cm) and 51% (2.6 cm) following manual cutting and cut stump–glyphosate treatments, respectively. In general, the greatest average diameter increases occurred following treatments that caused sustained reductions in vegetation, and in complexes where dense vegetation had overtopped conifers and suppressed their growth.

Conifer diameter was not affected by the single, manual cutting treatments studied in the *Fireweed, Ericaceous Shrub, Dry Alder, Wet Alder,* and *Aspen* complexes, by the single grazing treatments studied in the *Mixed Shrub* and *Fireweed* complexes, or by the foliar glyphosate treatment studied in the *Fireweed* Complex, even though diameter increment sometimes improved slightly or temporarily. We suggest that the lack of diameter responses in these complexes occurred for one or more of the following reasons:

1. Vegetation competition with well-established, thrifty lodgepole pine in the *Dry Alder* Complex was of low intensity, and control pine outgrew the alder canopy soon after those in the manual cutting treatment. We found that competition was of low to moderate intensity in the *Aspen* complex but long-term measurements are needed to determine when pine will outgrow the aspen canopy.
2. Brushing did not alleviate environmental factors (e.g., cold, wet soils) that appeared to override competitive effects in the *Wet Alder* Complex.
3. Vegetation reductions were too small and short-lived, and vegetation competition was neither important nor intense enough, for seedlings to respond, on average, in the *Fireweed* and *Mixed Shrub* complexes.
4. Conifer responses to brushing may have been delayed in the *Ericaceous Shrub* and *Wet Alder* complexes. Even though diameter was unaffected by brushing after 3–5 years, small decreases in height:diameter ratio and slow recovery of the vegetation may foreshadow future diameter increases. In these complexes, it is possible that seedlings were suppressed at the time of brushing and may eventually respond to release in the future. Responses may also have been delayed following girdling in the *Mixed Broadleaf-Shrub* Complex because girdled stems died slowly. Delayed responses are unlikely in the other complexes because either treated vegetation had already rebounded to control levels, both treated and control trees had outgrown neighbouring vegetation, or competition was of low intensity.

Conifer height was generally unaffected by brushing in our studies. The one exception was a 25% increase in Douglas-fir height 5 years following cut stump–glyphosate treatment in the *Mixed Broadleaf-Shrub* Complex. Many other studies demonstrate that height is less responsive than stem diameter to interspecific competition (Lanner 1985), and if height responds to release at all, it is usually delayed for several years (Simard and Heineman 1996a).

Whether short-term increases in growth following brushing result in greater yield at rotation, or shorter rotations, can only be determined with long-term measurement and maintenance of the studies. Several alternative outcomes have been discussed among foresters:

1. Yield may be unaffected because brushing has no effect on stocking, conifer species composition, or site productivity, and any short-term increases are masked by subsequent events in the life of the stand.
2. Yield may increase, but to a small degree, because growth of treated trees may parallel that of untreated trees once they have surpassed neighbouring vegetation. Theories (1) and (2) have been suggested for the herb- and shrub-dominated

complexes in particular. Convergence of treatment effects on 10-year conifer growth has similarly been observed following site preparation in interior British Columbia (Bedford and Sutton 2000).

3. Yield may increase substantially because growth curves of treated and untreated trees continue to diverge over time. This is commonly assumed to be the case for the *Mixed Broadleaf-Shrub* and *Aspen* complexes, but there is no published evidence for interior British Columbia conditions.
4. Yield in the *Mixed Broadleaf-Shrub* Complex may decrease as a result of brushing if mortality due to *Armillaria* root disease reduces stocking below site occupancy for conifers. Such unexpected effects have been reported for a variety of species, site conditions, and silvicultural treatments in British Columbia (e.g., Simard 1990b and unpublished data; Taylor et al. 1994; Simard and Heineman 1996a; Bedford and Sutton 2000).

Our neighbourhood analyses suggest that vegetation competition, considered over whole plantations, was of low or moderate importance and intensity to conifer diameter growth in the vegetation complexes studied (Table 144). This was evaluated on the basis of the adjusted r^2 (importance) and slope (intensity) of regression models (Weldon and Slauson 1986) relating conifer diameter to competition indices (cover, CRH, and broadleaf density) (see footnotes to Table 144 for definitions of low, moderate, and high importance or intensity). In general, tree size was highly variable under low to moderate levels of competition and constrained only by high levels of competition in localized, dense vegetation patches. More specifically, we found that vegetation competition was of low importance and low intensity in the *Fireweed* and *Dry Alder* complexes on mesic sites, which helps explain why conifers naturally outgrew these communities and did not respond to brushing treatments. In the *Fern* and *Mixed Broadleaf-Shrub* complexes, competition was of moderate importance and moderate intensity, which helps account for the larger conifer growth responses following brushing. In the *Mixed Shrub, Ericaceous Shrub,* and *Aspen* Complexes, competition was of moderate importance but low intensity, indicating that competition was an important determinant to overall conifer performance, but was too weak to illicit a substantial growth response to brushing. Conversely, competition was of low importance, but moderate intensity in the *Wet Alder* Complex, indicating that competition was locally intense, but not very important to overall conifer performance relative to other determinant factors (e.g., cold, wet soils). Other studies have also shown that neighbour competition is often of low to moderate importance to conifer performance in plantations, and that other factors can be of greater importance, including initial seedling size, damage incidence (e.g., by animals, insects, disease, frost), microsite, and genetic variability (Brand 1986; Coates 1987; Simard 1989a; Wagner et al. 1989; Wagner and Radosevich 1991; Burton 1993).

Competition thresholds for conifer growth were evident in all of the vegetation complexes studied, but were often diffuse in nature and varied considerably among replicate sites. This indicates that vegetation competition, and its effect on conifer growth, is variable both within and across sites. Average cover thresholds ranged between 18–28% for broadleaves in the *Mixed Broadleaf-Shrub* Complex, 13–31% for broadleaves in the *Aspen* Complex, 33–37% for alder in the *Dry Alder and Wet Alder* complexes, 35–46% for fireweed in the *Fireweed* Complex, and 68–78% for shrubs in the *Mixed Shrub* Complex. CRH thresholds and regression analysis generally followed similar patterns, indicating that the *Mixed Broadleaf-Shrub* was the most competitive complex to conifers, and the *Fireweed* and *Dry Alder* complexes were the least competitive.

We found that broadleaf thresholds for maximum conifer diameter growth in the *Aspen* Complex averaged 3180 and 2600 stems/ha for lodgepole pine and Douglas-fir, respectively. In the *Mixed Broadleaf-Shrub* Complex, the broadleaf thresholds averaged 2500, 3367, and 3664 stems/ha for hybrid spruce, lodgepole pine, and Douglas-fir, respectively. At the time the thresholds were derived, conifers were <13 years old (except for one site in the *Mixed Broadleaf-Shrub* Complex where they were 19 years old) and broadleaves were within 4 years of the age of the conifers (Table 144). These thresholds included broadleaf trees of all sizes, whether shorter or taller than the target conifers. In a separate study, Simard [2001, in review] derived two sets of thresholds for diameter growth of 9–13-year-old conifers in the ICHmw subzone of southern interior British Columbia: one using all-sized paper birch trees and another using only those paper birch trees that were taller than the target conifers. In that study, the density thresholds for western redcedar, Douglas-fir, and western larch were 4500, 4050, and 4000 birch stems/ha where all-sized paper birch were included, and 3325, 2575 and 733 birch stems/ha where only taller paper birch were included. Simard [2001, in review] found that broadleaf density thresholds declined with stand age, reflecting the dynamic nature of seral ICHmw forests. The thresholds were 1967, 485, and 370 taller broadleaf stems/ha in 25-year-old stands and 400, 173, and 40 stems/ha in 50 year-old stands for western redcedar, Douglas-fir, and western larch, respectively. The decline in thresholds corresponded with changes in the identity of

TABLE 144 *Summary of competition analyses*

Vegetation complex	BEC zone	# of sites used to determine thresholds	Conifer species	Conifer age[a] (yr)	Vegetation component used as a measure of competition[b]	Cover threshold[c] (%)	CRH threshold[d]	Density threshold[e] (stems/ha)	Competition importance[f]	Competition intensity[g]
Herb and low-elevation shrub complexes										
Fireweed	ICH	6	Se	0–4	Fireweed	46	60	-	Low	Low
	ESSF	13	Se	0–5	Fireweed	35	46	-	Low	Low
	ICH	5	Pl	0–5	Fireweed	40	49	-	Low	Low
Fern	ICH	4	Sx	1–4	Herbs	None	58	-	Moderate	Moderate
Mixed Shrub	ICH/ESSF	5	Sx	0–2	Shrubs	76	84	-	Moderate	Low
	ICH/ESSF	2	Cw	0–1	Shrubs	68	187	-	Moderate	Low
	ICH/ESSF	2	Fd	2–3	Shrubs	78	48	-	Moderate	Low
High-elevation shrub and herb complexes										
Ericaceous Shrub	ESSF	8	Se	0–9	Shrubs	52	73	-	Moderate	Low
Subalpine Herb	ESSF	1	Se	0	Herbs	None	184	-	Low	Low
Tall shrub complexes										
Dry Alder	MS	4	Pl	5–11	Alder	33	38	-	Low	Low
Wet Alder	ICH/ESSF	3	Se	5–10	Alder	37	107	-	Low	Moderate
Broadleaf complexes										
Aspen	IDF/MS	6	Pl	2–10	Aspen	31	31	3180	Moderate	Low
	ICH	4	Fd	2–10	Aspen	21	19	2400	Moderate	Low
Mixed	ICH/IDF	14	Fd	2–19	Broadleaves	28	39	3664	Moderate	Moderate
Broadleaf–Shrub										
	ICH	3	Pl	3–11	Broadleaves	18	15	3367	Moderate	Moderate
	ICH	3	Sx	1–13	Broadleaves	20	27	2500	Moderate	Moderate

[a] Age of conifers used in the threshold determinations.

[b] Vegetation component used in determinations of cover, CRH, and density thresholds (notes c, d, e).

[c] A threshold for conifer diameter was determined using cover of the chosen vegetation component.

[d] A threshold for conifer diameter growth was determined using CRH, which was calculated as: CRH = ("vegetation component" cover * "vegetation component" modal height)/conifer height.

[e] A threshold for conifer diameter growth was determined using the density of broadleaf stems.

[f] Competition importance was evaluated based on the adjusted r^2 values of simple linear regressions relating conifer diameter to competition index (cover, density, or CRH).

[g] Competition intensity was evaluated based on the slope of simple linear regressions relating conifer diameter to competition index (cover, density, or CRH).

the most important and intense competitors with stand age, from broadleaves to conifers, and changes in stand structure as stands self-thinned and stratified according to species height growth patterns.

Thresholds derived in this study varied among biogeoclimatic zones according to environmental limitations, such that conifers had higher thresholds (i.e., tolerated more competition) in milder than harsher climates within a particular vegetation complex. Thresholds also usually varied among conifer species along traditional patterns of shade tolerance, such that shade tolerant conifers generally had higher thresholds than intolerant conifers within a particular vegetation complex and biogeoclimatic zone. One exception was the *Mixed-Broadleaf Shrub* Complex, where there was little pattern in broadleaf density thresholds among moderately shade tolerant conifers (hybrid spruce, lodgepole pine, and Douglas-fir). In the study by Simard [2001, in review], threshold densities were also similar among conifers when all paper birch were included in the calculation, but closely followed traditional patterns of shade tolerance when only taller paper birch were included (western redcedar>Douglas-fir>western larch). Density thresholds for lodgepole pine were similar in the two broadleaf complexes, but those for Douglas-fir were greater in the *Mixed Broadleaf-Shrub* Complex than the *Aspen* Complex. We think this is because Douglas-fir growth is slower relative to neighbouring broadleaf trees and is more severely affected by soil water limitations in the dry belt *Aspen* Complex than the wet belt *Mixed Broadleaf-Shrub* Complex, whereas lodgepole pine performs well across a broad range of environmental conditions.

Our analyses of competition importance, intensity, and thresholds showed that vegetation competition was an important constraint to only a portion of conifers in the young plantations we studied. Averaged across all sites, only 30% of untreated conifers occurred in competitive environments above the thresholds. Brushing was applied to all trees to relieve competition constraints, as is usually done in operations, but only a portion of treated trees responded. We found, on average, that only 5% of treated trees achieved maximum growth (defined by 80% of the size of the largest tree) measured on the sites. The remaining 95% were growing at slower rates, probably because other growth-limiting constraints were not relieved by brushing. This, together with the patchiness of vegetation, implies that the broadcast approach to brushing, such as has been common in the past, may not be necessary. Instead, selective treatments could focus on competition-stressed trees only, possibly reducing brushing costs and preserving, as much as possible, the plant communities and their roles in succession.

The effect of broadleaf trees on conifer productivity in southern interior *Mixed Broadleaf-Shrub* and *Aspen* complexes is a contentious issue. Several short-term experiments, retrospective studies, process studies, and modelling studies (e.g., Simard 1990a, Sachs 1996, Simard and Heineman 1996a, Wang 1997, Simard and Hannam 2000, Comeau et al. 1999, Simard [2001, in review]) indicate that conifer productivity can be maintained in the presence of broadleaf trees, but there is little agreement on management of the composition (density and proportion of species) and dynamics of the mixtures. Some of the disagreement originates from the variability that exists among ecosystems, differences in methods of data collection and analysis, and differences in viewpoints on stand dynamics. Long-term experiments should provide answers to some of the questions. Different theories regarding broadleaf effects on yield of concurrently established conifers may be summarised as follows:

1. Yield may be substantially diminished at the relatively high density thresholds for taller broadleaves found in this study and Simard (2001, in review). At these densities, broadleaves will eventually suppress conifers and dominate the stands for a long period of time.
2. Yield may not be diminished at the relatively high density thresholds for taller broadleaves found in this study and Simard (2001, in review). This follows threshold theory that has been applied to forest stands, where relationships of growth to competition are described using ceiling functions (constraints) because individual tree size is highly variable under low competition (due to other limiting factors) and suppressed under high competition (Wagner et al. 1989, Burton 1996). Management to these thresholds would involve selective brushing of suppressed conifers. Conifers would naturally outgrow broadleaf neighbours according to height growth curve predictions in mixed stands. The appropriate density thresholds vary with site conditions.

3. Yield may be diminished at relatively low broadleaf density thresholds if brushing to meet these thresholds results in increased *Armillaria* mortality, or has other unexpected effects, and reduces conifer stocking below site occupancy.
4. Yield may not be diminished at relatively low broadleaf density thresholds. This theory, as well as (1), follows yield/density theory derived from agricultural studies, and commonly applied to forest stands, where least-square regression is used to describe relationships where individual plant size declines log-linearly with increasing weed density in fully occupied plots (Shinozaki and Kira 1956). Management to these low thresholds may involve broadcast brushing, with no or low retention of non-threatening broadleaf trees. Conifers will dominate the stands through rotation. Density thresholds are portable across a broad range of site conditions.

The effects of brushing on the height and cover of individual species or groups of species (i.e., herbs, shrubs, broadleaf trees) varied depending on the vegetation complex and type of treatment applied (Table 145). Here we discuss treatment effects and rates of recovery within various vegetation complex groupings.

Fireweed, Fern, and *Mixed Shrub* Complexes

Manual cutting, sheep grazing, and foliar glyphosate were used to reduce vegetation competition in the highly productive *Fireweed, Fern,* and *Mixed Shrub* complexes that occur in the interior wet-belt. Single-pass manual cutting and grazing treatments had minor, short-lived effects on herbs and shrubs in both the *Fireweed* and *Mixed Shrub* complexes. Most plant species recovered from these treatments within the season of application, which was usually too soon to release suppressed seedlings. In contrast, foliar glyphosate (1.4–2.1 kg ai/ha) reduced abundance of herbs, ferns, and shrubs for at least 5 years after application to the *Fireweed* and *Fern* complexes. In both complexes, the intensity and duration of vegetation control was sufficient to release seedlings, but only those in the *Fern* Complex significantly increased in diameter. The *Fireweed* Complex is sparser and less competitive than the *Fern* Complex on mesic sites, and the lower intensity and importance of competitive effects may explain why seedlings did not respond to the large and sustained vegetation reductions.

Ericaceous Shrub Complex

Ericaceous shrubs, mainly rhododendron, false azalea and *Vaccinium* spp., recovered slowly following single-pass manual cutting in the *Ericaceous Shrub* Complex, supporting the results of other studies (Coates et al. 1991). Manual cutting effects were sufficient to improve conditions for Engelmann spruce seedling survival, and to allow minor growth increases. Shifts from *Ericaceous Shrubs* towards a *Subalpine Herb* plant community have been observed following foliar glyphosate or mechanical site preparation (Boateng and Comeau 1997a), but this did not occur following the minor shrub canopy reductions made by manual cutting in our study.

Dry Alder and *Wet Alder* Complexes

Alder height and cover were dramatically reduced by single-pass manual cutting treatments applied from late June to mid-September in the *Dry Alder* and *Wet Alder* complexes. In both communities, alder recovered to approximately half of control levels within 3 years. Other shrub and herb species were not affected by the cutting treatments, and did not increase in abundance following removal of the alder canopy. This agrees with other *Dry Alder* manual cutting studies (Simard and Heineman 1996c). Glyphosate application to the *Dry Alder* Complex, on the other hand, has been shown to severely suppress alder for a much longer period, and has stimulated increases in understorey shrub and herb layers (Simard 1990b). In the *Wet Alder* Complex, shifts towards more competitive fireweed- or herb-dominated communities have also been documented following glyphosate application or mechanical site preparation (Stathers et al. 1994). Conifer seedling survival and growth did not improve following manual cutting in either the *Dry Alder* or *Wet Alder* complexes, but for different reasons in the two communities.

In the *Dry Alder* Complex, this and other studies have shown that lodgepole pine responds little or not at all to alder reductions by either manual or chemical means, mainly because interspecific competition is not severe. Pine naturally outgrows alder canopies within 10–15 years of establishment in the dry belt. In the *Wet Alder* Complex, spruce seedlings did not respond to vegetation reductions, possibly because other growth limitations (most likely cold, wet soils) were not relieved, and because alder sprouts were growing at faster rates than the conifers. That spruce was 4–6 years old at the time of brushing may also have been an important factor.

Mixed Broadleaf-Shrub and *Aspen* Complexes

Manual cutting, girdling, and cut stump–glyphosate were studied in the *Mixed Broadleaf-Shrub* Complex. Height of paper birch trees was immediately reduced by manual cutting, but sprouts grew in height at rates that were at least as fast as neighbouring Douglas-fir and lodgepole pine, and were approximately half the conifer height after 5 years.

TABLE 145 *Summary of vegetation responses*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Years to return to control cover	Years to return to control height	Remarks about vegetation responses	Were vascular plant richness and diversity affected?	Remarks about the effects of brushing on vascular plant richness and diversity
Herb and low-elevation shrub complexes										
Fireweed	ESSF/ ICH	Se 2–4 years	Manual	3	Fireweed	<1	<1	• Vegetation height and cover had returned to control levels before the first-year assessment was carried out.	NO	• Manual cutting had no significant effects on vascular plant species richness or diversity.
					All vegetation	<1	<1			
					Herbs	<1	<1			
					Shrubs	<1	<1			
Fireweed	ICH/ ESSF	Pl 1–3 years	Manual	5	Fireweed	<1	<1	• Vegetation height and cover had returnedto control levels before the first-year assessment was carried out.	NO	• Manual cutting had no plant significant effects on vascular plant species richness or diversity.
					All vegetation	<1	<1			
					Herbs	<1	<1			
					Shrubs	<1	<1			
Fireweed	ESSF/ ICH	Se 1–5 years	Glyphosate	5	Fireweed	>5	>5	• After 5 years, fireweed had recovered to an average 15% cover and 100 cm tall in treated plots, compared to an average 46% cover and 115 cm tall in the control.	NO	• Foliar glyphosate application had no significant effects on vascular plant species richness or diversity.
					All vegetation	>1 but <3	>1 but <3			
					Herbs	>1 but <3	>1 but <3			
					Shrubs	>1	>5			
Fireweed	ESSF	Se 0–5 years	Grazing	1	Fireweed	<1	<1	• Herb height continued to be reduced by grazing after 1 year, but otherwise, vegetation had returned to control levels before the first-year assessment was carried out.	NO	• Grazing had no significant effects on vascular plant species richness or diversity.
					All vegetation	<1	<1			
					Herbs	<1	<1			
					Shrubs	<1	>1			
Fern	ICH	Sx 2–4 years	Glyphosate	5	Lady fern	>5	>5	• Reductions in vegetation abundance were most pronounced in the first year following glyphosate application.	NO	• Foliar glyphosate application had no significant effects on vascular plant species richness or diversity. • Two berry-producing shrubs and several herbs tended to decrease in abundance.
					Thimbleberry	>3 but <5	>5			
					All vegetation	>5	>5			
					Herbs	>5	>3 but <5			
					Shrubs	>1 but <3	>5			

TABLE 145 *Continued*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Years to return to control cover	Years to return to control height	Remarks about vegetation responses	Were vascular plant richness and diversity affected?	Remarks about the effects of brushing on vascular plant richness and diversity
Mixed Shrub	ICH/ ESSF	Sx 1 year	Manual	3	All vegetation Shrubs Herbs	<1 >1 but <3 <1	>1 but <3 <1 <1	• Reductions in vegetation abundance were significant in the first year after manual cutting, but the actual reductions were small (i.e., 4-cm difference in vegetation height and 9% (41 vs. 50%) difference in shrub cover). • Herb cover increased briefly following cutting, but the effect was gone by year 3.	YES	• Manual cutting reduced vascular plant species diversity slightly in year three. • There were no significant effects on species richness.
Mixed Shrub	ICH/ ESSF	Sx 1–2 years	Sheep grazing	1	All vegetation Shrubs Herbs Fireweed	<1 <1 <1 >1	<1 <1 <1 >1	• Fireweed abundance was reduced for at least 1 year because it is a preferred forage for sheep.	NO	• Grazing had no significant effects on vascular plant species richness or diversity.
High-elevation shrub complexes										
Ericaceous Shrub	ESSF	Se 0–2 years	Manual	5	Shrubs Herbs All vegetation	>1 but <3 <1 >1 but <3	>1 but <3 <1 >1 but <3	• Vegetation cover and height were significantly reduced for 1 year, but reductions were relatively small (i.e., manual cutting reduced all vegetation height from 90 to 76 cm). • The small magnitude of the treatment effects is due partly to measurement methodology (see Section 7).	YES	• Manual cutting increased vascular plant species diversity for 3 years, but the difference was gone by year 5. The difference reflects a minor, short-lived reduction in the dominant shrub species. • Species richness was not significantly affected by manual cutting.
Tall shrub complexes										
Dry Alder	MS	Pl 5 years	Manual	5	Alder Shrubs Herbs	<1 >3 but <5 <1	>1 but <3 <1 <1	• Differences in alder cover were not significant because of large variability between sites. • After 5 years, 54% of alder had sprouts and they averaged 104 cm tall. • The reduction in shrub cover mainly reflects a reduction in alder abundance. • Herb abundance did not increase in response to removal of the alder canopy.	NO	• Manual cutting had no significant effects on vascular plant species richness or diversity.

TABLE 145 *Continued*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Years to return to control cover	Years to return to control height	Remarks about vegetation responses	Were vascular plant richness and diversity affected?	Remarks about the effects of brushing on vascular plant richness and diversity
Wet Alder	ESSF	Se 4–6 years	Manual	3	Alder	>3	>3	• Alder height and cover were significantly reduced for at least 3 years. • After 3 years, 58% of alder had sprouts, and they averaged 73 cm tall.	YES	• Manual cutting significantly reduced species richness in year 1 but the difference was gone by year 3. • There were no significant effects on species diversity.
					Shrubs	>3	>3			
					Herbs	<1	<1			
Tall shrub complexes										
Aspen	IDF/ MS	Pl 7–10 years	Manual	3	Aspen	<1	(see remarks)	• Reductions in aspen height were not significant because there was large variability across the study sites (cutting was spread across 2 years on one site). After 3 years, aspen height was reduced to 194 cm in the treatment vs. 510 cm in the control (p = 0.11). • 94% of stumps suckered, and suckers grew to an average height of 138 cm during the 3 years following cutting. • Herb cover decreased slightly in the first year after cutting, possibly because it was pressed by aspen slash.	NO	• Manual cutting had no significant effects on vascular plant species richness or diversity.
					Shrubs	<1	<1			
					Herbs	>1 but <3	<1			
Mixed Broadleaf-Shrub	ICH/ IDF	Fd 5–6 years	Manual	5	Broadleaves	<1	>5	• Broadleaves were 386 cm tall in the cutting treatment compared to 688 cm tall in the control after 5 years. • 86% of birch stumps had sprouts and they averaged 253 cm tall after 5 years.	NO	• Manual cutting had no significant effects on vascular plant species richness or diversity.
					Shrubs	<1	>3 but <5			
					Herbs	<1	<1			
Mixed Broadleaf-Shrub	ICH	Pl 3–10 years	Manual	5	Broadleaves	<1	>5	• Broadleaves were 329 cm tall in the cutting treatment compared to 504 cm tall in the control after 5 years. • 67% of birch stumps had sprouts, and they averaged 200 cm tall after 5 years.	NO	• Manual cutting had no significant effects on vascular plant species richness or diversity.
					Shrubs	<1	>3 but <5			
					Herbs	<1	<1			

TABLE 145 *Concluded*

Vegetation complex	BEC zone	Crop tree species and age[a]	Brushing method	Years measured	Vegetation component	Years to return to control cover	Years to return to control height	Remarks about vegetation responses	Were vascular plant richness and diversity affected?	Remarks about the effects of brushing on vascular plant richness and diversity
Mixed Broadleaf-Shrub	ICH	Fd 8–9 years	Cut stump–glyphosate	5	Broadleaves	>5	>5	• Broadleaves in the treatment had 15% cover and were 385 cm tall after 5 years. Those in the control had 70% cover and were 952 cm tall. • 24% of birch stumps had sprouts and they averaged 273 cm tall after 5 years.	NO	• Cut stump–glyphosate had no significant effects on vascular plant species richness or diversity.
					Shrubs	>1 but <3	>3 but <5			
					Herbs	<1	<1			
Mixed Broadleaf-Shrub	ICH	Fd 5–17 years	Girdle	5	Broadleaves	>1 but <3 (see remarks)	<1 (see remarks)	• Girdling effects on broadleaf cover were significant for only 1 year because of large variability between sites in the rate at which girdled stems died. In year 5, broadleaf cover was 10%. • Girdling effects on broadleaf height were not significant because girdled stems died slowly. • 11% of birch stumps had sprouts and they averaged 205 cm tall after 5 years.	YES	• Vascular plant species diversity was significantly greater in the girdling treatment than the control in the first year. • The difference was gone by year 3. • Girdling had no effect on species richness.
					Shrubs	<1	<1			
					Herbs	<1	<1			

[a] Age (years since planting) at the time of brushing.

Cutting date did not appear to affect sprout growth rates, but Peterson et al. (1997) suggest that cutting in May-June may reduce sprouting because of seasonal carbon allocation patterns. Shrubs were also temporarily reduced in height because they were cut at the same time as broadleaves, but otherwise shrubs and herbs neither decreased nor increased in abundance following broadleaf canopy removal. Girdling in August-October slowly killed birch trees so that the treatment was not fully expressed until 3 years post-treatment. Five years after treatment, broadleaves in the girdling treatment had only one-quarter the cover of those in the control, and little sprouting had occurred. Herb abundance increased temporarily, but the plant community appeared unaffected 5 years after the girdling treatment was applied. The cut stump-glyphosate treatment (full concentration applications at 0.74–3.20 kg ai/ha) had the most dramatic and prolonged effect on the *Mixed Broadleaf–Shrub* Complex. Five years after application, fewer than one-quarter of broadleaf stumps had sprouts, and crown cover was approximately one-quarter that of the control. Shrub height was also reduced for 3 years by cutting; otherwise, shrub and herb layers were unaffected by the treatment. Douglas-fir growth rate increased following all of these treatments, but the increase was greatest following cut stump–glyphosate application. All treatments resulted in a change in height dominance within the stands from mixed broadleaf/conifer to conifer-dominated. The conversion was most dramatic following cut stump–glyphosate treatment, where sprouting of birch was minimal.

Manual cutting in the *Aspen* Complex immediately reduced aspen height, which was still less than half that of neighbouring lodgepole pine after 3 years. Similar height growth rates of lodgepole pine and aspen should ensure that pine continues to dominate these stands, resulting in a shift in height dominance from a mixed to a conifer-dominated stand. Cutting aspen had no effect on understorey shrubs or herbs.

Species Richness and Diversity

None of the brushing treatments had a sustained effect on either vascular plant species richness (number of species) or diversity in any of the vegetation complexes studied (Table 145). (The diversity indices used in this study, Shannon-Weaver's and Simpson's, incorporate species richness and evenness, which is the proportional abundance of species). These results agree with findings in other brushing studies in early seral stands in British Columbia (Haeussler et al. 1999; Boateng et al. 2000). However, we did find a few short-lived differences in species richness and diversity. These are discussed below in the context of trends in increasing or decreasing abundance of individual species within groupings of vegetation complexes.

Trends of Increasing or Decreasing Abundance for Individual Plant Species

Fireweed, Fern, and *Mixed Shrub* complexes

Manual cutting treatments had little effect on the abundance of individual species in the *Fireweed* and *Fern* complexes because vegetation recovered very rapidly. In the *Mixed Shrub* Complex, species diversity decreased 3 years after manual cutting, which was associated with treatment reductions in the abundance of three common shrubs (thimbleberry, elderberry, and black huckleberry), four herbs (spiny wood fern, oak fern, small twisted stalk, and dandelion), and grasses. However, we expect this will be a temporary change because the *Mixed Shrub* community was quickly recovering to control conditions.

Vegetation rapidly returned to control levels in the *Fireweed* and *Mixed Shrub* complexes following single-pass grazing treatments, and we did not detect any trends of increasing or decreasing abundance among individual plant species. However, sheep grazing has the potential to cause species shifts because of sheep preferences for certain forage species, and because of the potential for introduction of exotic species. Species shifts should be carefully considered in grazing prescriptions because they do not always favour seedling performance (Newsome et al. 1995). Greater potential for changes in the plant community exist with 2–3 seasons of grazing, which appears necessary for seedling release in dense, competitive communities.

Foliar glyphosate treatments consistently reduced the abundance of several herb species (e.g., lady fern, bracken, fireweed) in the *Fern* and *Fireweed* complexes during the study period. This was expected because those species were targeted by the brushing treatments. Of some concern, however, are the reductions in abundance of berry-producing shrubs associated with these communities, including: black huckleberry, oval-leaf blueberry, black gooseberry, thimbleberry, and Sitka mountain ash. Chemical brushing treatments could have negative consequences for wildlife species that browse these berries, and may be opposed by the public or special-interest groups. However, compared with manual treatments, chemical brushing is currently applied on a relatively small scale in the southern interior. As with other complexes, some low-stature herbs increased in response to decreasing abundance of taller herbs and shrubs. In this case, grasses and purple-leaved willowherb increased following glyphosate application in the *Fireweed* Complex.

Ericaceous Shrub complex

In the *Ericaceous Shrub* Complex, the diversity of vascular plant species increased 3 years following manual cutting. Decreased abundance of prominent shrubs, such as white-flowered rhododendron, Sitka mountain ash, and thimbleberry allowed several minor herb species to invade or increase in cover. The increase in diversity reflects a more even distribution of cover over a greater number of species, compared with the control where the community was dominated by a few, high-cover shrub species. The difference was short-lived, however, and disappeared by the fifth-year assessment.

Dry Alder and *Wet Alder* complexes

Few trends of increasing or decreasing abundance of individual species were observed following manual cutting in these communities. Greater light availability to the low herb layer following removal of the alder canopy allowed bunchberry to increase in abundance in the *Wet Alder* Complex.

Mixed Broadleaf-Shrub and *Aspen* complexes

All treatments applied to these communities resulted in decreases in the abundance of broadleaf species because they were the targets of treatment. At the same time, cover of cut shrubs, such as willow, usually increased because of sprouting. Several herb species increased in abundance following most brushing treatments, including fireweed, Hooker's fairy bell, strawberry, tiger lily, and rattlesnake plantain. Dandelion and thistle, both common weeds, also increased following brushing. The implications of these changes for wildlife are unknown, but most are probably minor (Sullivan et al. 1998; Boateng et al. 2000). One possible exception is the reduction in tall broadleaves, which could affect the availability of perching and nesting sites for birds (Machmer and Steeger 1995). Sprouts that occur following manual cutting are known to increase summer browse for moose and deer, but winter browse may decrease because fewer shoots remain above the snowpack (Simard and Heineman 1996a; Peterson et al. 1997). Brushing treatments can also negatively affect the quality of paper birch by favouring smaller-diameter stems, and may therefore reduce the utility of birch for wood or other products.

Structural Vegetation Groups

Brushing had few effects on the structure of plant communities (according to the Shannon-Weaver and Simpson Diversity Indices), with some exceptions in the *Mixed Broadleaf-Shrub, Ericaceous Shrub,* and *Aspen* complexes. In the *Mixed Broadleaf-Shrub* Complex, manual cutting and cut stump–glyphosate treatments resulted in an increase in the diversity of structural vegetation groups because of the decreased dominance of broadleaves and increased evenness among all plant species. These changes persisted throughout the 5-year measurement period. A similar increase in diversity was observed following manual cutting in the *Ericaceous Shrub* Complex because of reduced shrub dominance. In contrast, structural diversity decreased following girdling in the *Mixed Broadleaf-Shrub* Complex and manual cutting in the *Aspen* Complex. Prior to brushing, these stands were characterized by the presence of tall dominants, and their removal served to decrease structural diversity.

Some common trends in conifer and plant community responses to brushing occurred among the different vegetation complexes. These trends have improved our ability to predict where competition will be a problem and where brushing will be beneficial to conifer performance. In addition, they can help improve management recommendations regarding method, intensity, and timing of brushing treatments. Here we summarize important trends and management implications for the main groups of vegetation complexes studied, based on our own and other studies.

Fireweed, Fern, and *Mixed Shrub* Complexes

On circum-mesic sites, where vegetation in these complexes was moderately dense (<50% cover), seedlings performed well and have naturally outgrown, or are projected to outgrow, vegetation within the free-growing window. The results from our study sites indicate that brushing was not necessary to ensure good plantation performance. However, seedling survival can be at risk in the dense herb or mixed shrub complexes that sometimes develop in moist to wet ecosystems, in wetter ICH subzones, and at high elevations where the growing season is short. Most mortality occurs soon after plantation establishment on those sites, well before the majority of brushing operations are carried out. These wetter sites should be site prepared soon after harvest (within 1–2 years of harvest), planted promptly with large-caliper, high-quality stock, and, if necessary, brushed within 1–2 years of planting. Where these complexes are well developed, single-manual or grazing treatments appear to be ineffective at improving the seedling-growing environment. Three consecutive manual cutting passes (best applied in summer), three consecutive grazing seasons, or a single glyphosate application, which result in sustained vegetation reductions, should be used instead. Three manual treatments average $1,614/ha and three grazing passes average $744/ha, compared to $700/ha for a single ground chemical treatment (Table 1).

Ericaceous Shrub Complex

At high elevation, vegetation has indirect effects on frost, light availability, and to some extent, soil temperature. Prompt site preparation can discourage the *Ericaceous Shrub* and more competitive *Subalpine Herb* complexes, and relieve severe environmental constraints to some extent (Boateng and Comeau 1997a). In combination with the planting of high-quality stock, site preparation can facilitate the establishment of free-growing stands and reduce or eliminate the need for brushing. In our study, site preparation and planting occurred 3–4 years after harvest, and ericaceous shrubs were well established (46–82% cover, 103–135 cm height) at the time of brushing. Shrubs were manually cut once in variable, tree-centered radii, which was sufficient to ensure good survival and adequate growth rates of the 2-year-old spruce seedlings.

Dry Alder, Wet Alder, and *Willow* Complexes

In our study, conifers that established immediately after disturbance performed well and naturally outgrew the *Dry Alder* Complex in the MS zone. Similar results were found for the *Dry Alder* Complex, as well as the *Willow* Complex, in other brushing studies in the southern interior (Simard and Heineman 1996b, 1996c; Simard, Heineman, and Youwe 1998). Interspecific competition between conifers and shrubs in these communities was of low intensity, except in small, localized patches. Alder and willow play key roles in succession, site productivity, and wildlife habitat, and should not be brushed unnecessarily. Chemical brushing of the Dry Alder Complex has also been shown to reduce range value on some sites (Simard, Heineman, and Youwe 1998). Where brushing is used to release conifers growing inside dense alder or willow patches, a single manual cutting has been as effective at improving seedling performance as glyphosate treatments (Simard and Heineman 1996b, 1996c).

Conifers are not expected to outgrow the taller, denser *Wet Alder* Complex that develops on moist, rich sites in the ICH and ESSF zones. Plantation establishment is particularly problematic in alder swales that occur in a patchy mosaic with conifers prior to harvest. For conifer production, the *Wet Alder* Complex should be managed pre-emptively with prompt site preparation and planting. If brushing is necessary, chemical treatments are preferred over repeated manual treatments because of poor visibility in the dense brush, the potential for substantial accidental cutting of seedlings, and the high cost of repeated treatments.

Mixed Broadleaf-Shrub Complex

The *Mixed Broadleaf-Shrub* Complex is naturally clumpy. Dense patches of paper birch can suppress growth of conifers, whereas moderate densities on the same site appear to have small effects (<4050 total birch stems/ha or <2575 over-topping stems/ha for 5–13-year-old Douglas-fir, where birch established within 1–4 years of Douglas-fir) (this study and Simard [2001, in review]). Conifers can be expected to tolerate lower densities of birch if they are planted well after disturbance and into an established birch stand, as was found in studies by Simard and Hannam (2000) and Comeau et al. (1999). In our study, rarely were broadleaf densities so uniformly high that established conifers actually died, or appeared likely to die, from resource limitations. Comeau et al. (2000b) also documented that survival of established conifers has been unaffected by brushing treatments in British Columbia. Broadcast brushing of paper birch does consistently increase average conifer growth. However, many conifers perform well without brushing because not all are experiencing suppressive competition in the clumpy stands. Moderate densities of broadleaves have been shown to have a protective effect on conifers from *Armillaria* root disease, frost, and browsing (e.g., Perala and Alm 1990; Simard and Heineman 1996a). Broadleaf trees also provide important habitat for many creatures, from micro- to macroscopic, and play important roles in succession (Peterson et al. 1997). In developing brushing prescriptions, both potential conifer growth gains and potential losses associated with root disease or other factors should be considered. We recommend selectively brushing only those conifers that are suppressed by competition rather than using broadcast treatments. On sites with high levels of *Armillaria* inoculum, disease spread may be reduced by using chemical instead of manual treatments.

There are concerns that this management approach will result in broadleaf domination, conifer mortality, and the loss of plantations in the future. However, studies on competition dynamics in the *Mixed Broadleaf-Shrub* complex indicate that paper birch at moderate densities (below the thresholds identified in this study) becomes less competitive with conifers as stands age, it is outgrown by Douglas-fir by 50 years of age, and on productive sites where concern is greatest, it comprises a small portion of stand volume at 80–100 years of age (Cameron 1996; Wang 1997; Simard [2001, in review]; Simard and Sachs [2001, in review]). There may be some sites where paper birch is of sufficient density and productivity to reduce survival of neighbouring conifers, but the extent of their occurrence is unknown. Simard and Vyse (1992) found that average broadleaf density on 10-year-old clearcut ICH sites was usually <5000 stems/ha, regardless of site preparation method, which according to the study of Simard [2001, in review] is suggestive of moderate competitive conditions for conifers, except in localized patches. Broadleaf-dominated stands are rare following natural disturbance in the southern interior wet belt (Sachs et al. 1998), and the potential for them to increase following conventional harvesting and different methods of site preparation is poorly understood. The potential threat of low to moderate densities of paper birch on productive sites should be carefully evaluated in future studies.

Aspen Complex

In our study, lodgepole pine that had established immediately after disturbance performed well in association with the *Aspen* Complex in the drier, southern subzones of the IDF and MS zones. Interspecific competition between aspen and pine in these southern ecosystems appears to be much less intense than that between aspen and pine or spruce in northern ecosystems, probably because pine and aspen tend to grow at similar rates in the south. Aspen provides many ecological benefits, similar to those described above for paper birch, which should be considered in development of brushing prescriptions. Our early results suggest that brushing of aspen may be avoided on southern IDF and MS sites without loss of conifer productivity. Where interspecific competition is intense in small, localized patches, selective manual cutting should sufficiently release individual conifers. Alternatively, girdling could be applied when the aspen is older, larger, and possibly more competitive. Girdling is advantageous in that (a) treatment can be postponed until competition problems, if they occur at all, are fully expressed, and (b) conifers can better acclimate to the changed environment because the girdled trees die slowly. Girdling could be applied in a similar manner in the *Mixed Broadleaf-Shrub* Complex.

The PROBE program expands our understanding of interspecific competition between conifers and early seral plant communities in young plantations in the southern interior. The main contributions of the work, including our improved ability to assess, predict, and treat vegetation problems, need to be further expanded to include a wider array of vegetation complexes, treatments, and ecosystem effects. We see several interrelated directions as priorities for further research.

1. The effects of the brushing treatments on growth, yield, and stand dynamics need to be evaluated over the long term. This represents an important information gap both locally and worldwide. The PROBE plots were designed to meet the minimum size criteria for Permanent Sample Plots as established by the Forest Productivity Council of British Columbia (1990), and therefore can continue to be maintained and measured through to rotation age. This will require that full-stem DBH tallies are completed and permanently marked in large plots overlain on the existing treatment and control plots of each PROBE installation, as outlined by Biring et al. (1998). This should be completed after the 10-year re-measurement of each installation.
2. Brushing effects on yield at rotation should be modelled to fill short-term information gaps in Timber Supply Reviews. Existing vegetation management and yield models need to be reviewed for their applicability to southern interior conifer species and vegetation complexes. Different models may be appropriate for herb/shrub complexes than broadleaf complexes. A meta-model approach should be explored, where vegetation management models provide input data for stand structure or growth and yield models. Vegetation management models that should be considered include BRITE (Comeau, pers. comm., 2000), SYSTUM-1 (Ritchie and Powers 1993), RVMM (Shula and Marshall 1998), and a New Zealand growth model by Mason et al. (1997). Mixed species stand models that should be reviewed include MGM (Titus 1999), SORTIE (Pacala et al. 1993, 1996), TASS (Mitchell 1975), and PROGNOSIS (Greenough et al. 1999).
3. Additional replicate sites are needed for approximately 30 treatments, where we currently have only 1–2 replicates, before we can statistically evaluate responses to brushing. For treatments that currently have 3–4 replicate sites (i.e., those reported here), replication should be increased to 5 in order to improve the power of the parametrical statistical tests. Three replicates represent the minimum requirement for ANOVA and results in low power to detect treatment differences, especially if the differences are small. At present, the variability among replicate sites is indicated in the reported ANOVA results and standard errors, and further information can be derived by the reader by calculating confidence intervals as described in Section 3 (Methods). To address statistical power and variability for future analysis of these treatments, of greatest importance is to increase replication in those treatment cells where (a) replicates are from more than one biogeoclimatic zone (e.g., ICH and ESSF zones in *Mixed Shrub* and *Fireweed* complexes), (b) the vegetation complex is quite variable from site to site (e.g., *Mixed Shrub* and *Fern* complexes), and (c) brushing treatments are variable (e.g., different sized radii in tree-centred manual brushings).
4. Vegetation complexes examined in this study were classified based on published descriptions by Kimmins and Comeau (1990). Most complexes were well defined with one or two dominant herb, shrub, or broadleaf species. However, the *Mixed Shrub, Fern,* and *Fireweed* complexes are comprised of several common species that vary in their relative abundance. For some PROBE sites, the plant community did not correspond well with complex definitions, or was similar to more than one complex, and a qualitative judgement was therefore made in assignment to a particular treatment cell. Further research and analysis is needed in classification of vegetation complexes and description of seral vegetation by ecosystem unit. In addition, better identification of problematic sites is needed.
5. Identification of competition thresholds for conifer growth lacks rigorous quantitative techniques. Alternative methods need to be investigated or developed for objectively identifying

competition thresholds and examining their variability. In addition, facilitation thresholds were evident in most complexes, but remain to be quantified. Facilitation thresholds mark a minimum vegetation level necessary for optimal conifer growth, below which performance is depressed. Our neighbourhood data repeatedly showed that sparsely covered ground was a suboptimal environment for tree growth. The regression analyses used to evaluate competition importance and intensity could also be strengthened and expanded. A variety of competition indices could be explored and different models tested to determine if the relationships can be improved. Different models could be instructive in assessing competition processes (e.g., Newton and Jollife 1998; Wagner and Radosevich 1998; Simard and Sachs [2001, in review]).

6. The conifer response and vegetation data could be analysed using alternative approaches, including repeated measures MANOVA, Bayesian analysis, and multivariate analysis. Repeated measures MANOVA will be particularly useful after 10-year response data has been collected and can be used to examine treatment by time interactions. Additional ANOVAs, where replicate sites are pooled over more than one biogeoclimatic zone or vegetation complex for a particular treatment, could also be conducted in order to increase the power of the tests and to test for interactions among zones or complexes. Bayesian analysis could be used to examine probabilities of reaching biological or management goals under various treatment regimes. Multivariate analysis could be used to examine changes in plant community composition over gradients of treatment intensity. For survival, precision in estimates could be increased by using stocking survey data instead of target tree data because the sample size is much greater (>200 versus 36 trees). These analytical tools could be used to present data in alternative ways that would highlight particular features of the data sets for different end-users.
7. Broadcast manual and chemical treatments remain the core focus of brushing programs in the southern interior of British Columbia, but variations to these treatments are being applied operationally in many areas. For example, paper birch and trembling aspen are being retained in low densities in the *Aspen* and *Mixed Broadleaf-Shrub* complexes during manual and chemical brushing treatments. Shrubs and herbs are being manually brushed multiple times and during different times of the growing season in the *Mixed Shrub, Fireweed,* and *Fern* complexes. Conifers are also being treated using tree-centred, selective approaches rather than broadcast treatments. These operationally applied treatments need to be evaluated to determine their efficacy at releasing conifers from interspecific competition and creating free-growing stands.
8. Effects of brushing on ecosystem attributes other than conifer performance and plant community condition should be studied. The network of PROBE plots provide an excellent opportunity for other researchers to study more detailed ecosystem patterns and processes within an existing replicated and randomized framework. One example would be to expand studies of brushing effects on specific changes in plant community diversity and structure. We used published species diversity indices as well as our own structural diversity indices, but their power to detect subtle plant community changes was limited. In addition, brushing effects on wildlife species, particularly small mammals and birds, could be studied in relation to changes in habitat, building on the work of Sullivan (1985) and Sullivan et al. (1998). Another area in need of further study is the longer-term brushing effects on insect and disease patterns among conifers, deciduous trees and other plants in the community. Finally, our studies focused on the effects of competition, not competition processes. Detailed process studies would improve our ability to predict vegetation problems in other ecosystems and vegetation complexes.
9. Cumulative effects of silviculture practices, including brushing treatments, should be evaluated over large scales, particularly where tree species composition is affected. For example, reductions or increases in broadleaves may alter broadleaf patterns at large scales. Brushing treatments may be accompanied by spacing of less desirable conifers to encourage dominance by one or a few, favoured conifer species, which may affect composition and diversity of stand dominants. Because different species and combinations of species differ in their resistance and resilience to disturbance, broad changes in vegetation patterns as a result of brushing and other

silviculture practices may affect patterns of natural disturbances caused by wildfire, root disease, and insects (Turner et al. 1989). The cumulative effects of brushing treatments over large scales could be examined using landscape-level models that exist, such as TELSA (Kurz et al. 2000), or that can be developed using SELES (Fall and Fall 1999). As in (2) above, a meta-model approach could be explored, where vegetation management and yield models provide input data for a landscape model.

10. Further extension is needed to increase access of PROBE and other vegetation management information to silviculturists. An extension plan currently under development involves inclusion of PROBE results in field workshops, field handbooks, extension notes, newsletters, and web sites. For example, a series of district-based workshops could be conducted where results are reviewed in relation to local field conditions. In addition, an interactive, computer-based, expert system could be developed that provides end-users with (a) the most recent vegetation management research results, (b) projections of treatment effects on growth, yield and stand dynamics as well as attainment of management goals, and (c) guidance on development of vegetation management prescriptions.
11. Evaluation of operational silviculture treatment effects in relation to management and ecological objectives is needed for all major silviculture activities. This has long been recognised, a variety of programs have been attempted in the past, and committees continue to explore options. To our knowledge, there are currently no other broad programs in progress in the southern interior that measure silviculture treatment effects on conifer yield and plant communities other than those that inventory areas that are treated and administrative goals that are met. Common silviculture treatments that could be evaluated, in addition to brushing, include site preparation, planting, natural regeneration, spacing, thinning, pruning, and fertilisation. There is also a need to measure vegetation management treatments and other silviculture treatments in a range of silviculture systems, particularly partial canopy retention and partial cutting systems. Addressing treatments will require a series of integrated protocols that provide evaluations from pre-harvest to the next harvest.

In conclusion, PROBE has been an effective program for evaluating conifer and plant community responses to operational brushing. Combined with experimental results of other studies, this study has advanced our ability to assess, predict, and treat vegetation competition problems in young conifer stands. There is a critical need to continue remeasurement of the study sites, establish new installations to fill data gaps, and examine new techniques and practices. In addition, there is a need to further extend the information and develop new tools to support vegetation management decisions. The PROBE program may serve as a successful example for other programs aimed at evaluating silviculture treatment effectiveness.

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Appendix 1

Trends in Conifer and Vegetation Response in the *Willow* and *Pinegrass* Complexes

This section presents and discusses results for glyphosate application on a single site in each of the *Willow* and *Pinegrass* complexes. These treatments were insufficiently replicated for ANOVA because of lack of opportunity and funding to install more replicate PROBE sites. Nevertheless, these site-specific trends are presented so that the *Willow* and *Pinegrass* complexes, which are important vegetation communities for forest management in the southern interior of British Columbia, are represented in this report.

Introduction

This Appendix describes five-year responses of Douglas-fir and the *Willow* Complex to glyphosate spray on a single PROBE site in the IDF zone. Because there is only one site, statistical analysis cannot be carried out, and conclusions cannot be drawn regarding treatment effectiveness. However, we discuss trends in our results, and compare them with other studies reported in the literature. This Appendix is formatted similarly to sections in the main body of the report, but less emphasis is placed on PROBE results than on other, fully analyzed studies.

Description of the *Willow* Complex

A variety of willow species occur in the *Willow* Complex, but upland species such as Scouler's willow (*Salix scouleriana*), Sitka willow (*Salix sitchensis*), and Bebb's willow (*Salix bebbiana*) are the most common. In southern interior British Columbia, the *Willow* Complex occurs in the IDF, ICH, MS, and ESSF biogeoclimatic zones.

Of the upland willows that commonly occur in the southern interior *Willow* Complex, Bebb's willow and Sitka willow grow best on wetter sites, and Scouler's willow on somewhat drier sites. Soil texture, aspect, slope, elevation, and topography apparently do not affect the distribution or abundance of willow, except as they relate to soil moisture regime (Porter 1990). In southern interior British Columbia, the *Willow* Complex develops abundantly mainly on sites that are moist to wet (Kimmins and Comeau 1990). Although willow tolerates a wide variety of nutrient conditions, it generally grows best on medium to rich sites (Rawson 1974; Haeussler et al. 1990).

Development of the *Willow* Complex

The *Willow* Complex develops following major disturbances that remove or reduce the forest canopy, such as harvesting or wildfire. Willows are very shade-intolerant and do not grow well under low light conditions; however, in full sunlight they can dominate other vegetation (Rawson 1974). Even where willow occurs at low density under the forest canopy, it potentially can develop into a robust shrub community following harvest. The *Willow* Complex can develop from seed or through rapid sprouting from relatively few seed-origin stems, depending on the nature of the disturbance.

Willow produces abundant seed that germinates readily on exposed mineral soil (Grime 1979, cited by Haeussler et al. 1990), especially in full sunlight (Brinkman 1974). Therefore, treatments that expose mineral soil (e.g., severe wildfires, brushblading, V-plowing) promote development of the *Willow* Complex, particularly when they occur near willow seed sources and immediately before seed dispersal (Boateng and Comeau 1997d). However, it can take several years for seed-origin willow to become dense enough to impede conifer regeneration (Eis 1981). Spread of the *Willow* Complex can be much more rapid where harvesting or site preparation treatments have cut existing willow stems and stimulated sprouting, or have mixed stem and root fragments into the soil causing new plants to regenerate (Haeussler et al. 1990; Porter 1990; Boateng and Comeau 1997d).

Fire generally stimulates vigorous sprouting of willow (Haeussler et al. 1990; Porter 1990), and is used as a wildlife management tool to rejuvenate older willow stands (Haeussler et al. 1990). In the SBS and BWBS zones of northern British Columbia, the *Willow* Complex is particularly prevalent on sites with a history of repeated fires (Haeussler et al. 1990). However, prescribed burning has also been observed to reduce willow abundance in southern interior clearcuts (Haeussler et al. 1990).

Interactions with conifer seedlings

Many species of willow occur in southern interior British Columbia, but it is mainly the juvenile growth of tall shrubs and low trees that compete with conifer seedlings. When mature, these willows do not form dense canopies, but in their juvenile form they produce numerous sprouts with large leaves, and can reduce the amount of light reaching seedlings (Haeussler et al. 1990). Willow grows best on wet, nutrient-rich sites, where it likely has little effect on soil water or nutrients, but may reduce the amount of light reaching conifers. Willow sheds its foliage every fall, and decomposition of the nutrient-rich litter likely improves nutrient availability to neighbouring conifers, as well as increasing site productivity.

Importance to wildlife and range

Willow is a valuable food for moose, deer, Rocky Mountain elk, muskrat, beaver, rabbits, hares, and many species of birds (Kufeld 1973; Rawson 1974; Porter 1990). Moose and deer browse on willow year-round, but it is particularly important as a winter food (Haeussler et al. 1990; Porter 1990). Willow also provides cover for mammals and birds (Rawson 1974).

Willow is foraged by domestic livestock as well as wildlife. It is a preferred forage for sheep (Newsome et al. 1995) and has medium–high importance for cattle (McLean 1979). Cattle will graze on willow foliage in summer months, and in the winter they will eat twigs up to 0.6-cm diameter in order to survive. In spring, willow foliage has a fairly high protein content and a low crude fibre content, but, as the season progresses, protein content drops and fibre content increases (McLean 1979). Given the importance of willow to wildlife and range, brushing treatments that reduce its abundance should be applied prudently.

Common brushing treatments in the *Willow* Complex

In southern interior British Columbia, chemical brushing is considered the most effective method of controlling the *Willow* Complex. Manual brushing treatments are also applied, but willow sprouts so vigorously following cutting that at least two passes are likely to be required. Young willow is a preferred forage for sheep, and grazing treatments have been found to reduce the abundance of willow less than 1.5 m tall (Boateng and Comeau 1997d). Common brushing treatments are described in Table A1.1.

Unreplicated Results

Ground foliar glyphosate application

The *Willow* Complex was brushed on an IDF site when Douglas-fir seedlings were 8 years old and willow was 278 cm tall and had 10% cover.

Description of the Study Site and Treatment

The site is located near the Nicoamen River in the Lillooet District of the Kamloops Forest Region. It is in the Cascade Dry Cool IDF variant (IDFdk2) at an elevation of 1080 m, and is on an east-facing, 25% slope. Soil moisture regime is submesic, and soils are sandy-loam in texture. The site was clearcut in 1977–1978, broadcast burned in 1978, and planted with Douglas-fir in 1982 and 1984. Glyphosate was applied in mid-August at a rate of 1.78 kg ai/ha as a broadcast spray using backpack sprayers.

Conifer response

Survival and vigour Douglas-fir seedlings were well established when brushing took place, and no mortality occurred in either the treatment or control during the 5 years following glyphosate application (Table A1.2). Most seedlings in both treatment and control plots improved in vigour, from moderate in the pre-treatment assessment to good in the first-year assessment. However, by year 5, seedlings in both the treatment and control were infested with aphids and overall vigour had returned to moderate. Few seedlings were of poor vigour in years 1–3, but in year 5, 15–20% were poor.

Growth There were no obvious growth trends among Douglas-fir seedlings as a result of brushing the *Willow* Complex with glyphosate (Table A1.2). Prior to treatment, average seedling stem diameter was 3.0 cm in the control versus 2.6 cm in the treatment, and 5 years later there continued to be a similar difference (5.5 cm in the control versus 5.0 cm in the treatment). Seedling height appeared to be negatively affected by glyphosate application; after 5 years, seedlings had grown to 247 cm in the control and only 201 cm in the treatment.

Competitive status Brushing the *Willow* Complex with glyphosate had an immediate effect on the competitive status of Douglas-fir seedlings (Table A1.2). Prior to treatment, only 16% of seedlings were free of surrounding vegetation but, 1 year later, 70% of treated seedlings were free of vegetation compared to 28% of control seedlings. Vegetation gradually recovered, and, by 5 years after brushing, 44% of seedlings were still free of surrounding vegetation in the glyphosate treatment, compared to only 6% in the control. The remaining seedlings were threatened rather than overtopped.

Vegetation response

It is difficult to evaluate treatment effects on vegetation abundance on this site because of pretreatment differences between the treatment and control, and because an ant infestation and droughty site conditions interfered with the effects of glyphosate on willow. Shrubs and willow were

TABLE A1.1 *Common brushing treatments applied to the Willow Complex in the southern interior of British Columbia*

Treatment	Objectives	Optimum timing	Suggested number of treatments	Tools	Average cost per ha[a]	Potential disadvantages
Foliar glyphosate spray (1.4–2.1 kg ai/ha)	1. Reduce light competition	Mid-October[b]	1	1. Backpack sprayer	$700	1. Cannot apply near waterways 2. Reduces wildlife forage 3. Difficulty in obtaining herbicide permits
Hexazinone spot soil application (10%)	1. Reduce light competition	Unknown	1	1. Spot gun	Unknown	1. Cannot apply near waterways or on coarse-textured soils 2. Reduces wildlife forage 3. Difficulty in obtaining herbicide permits
Manual cutting	1. Reduce light competition	Possible advantage in late summer[c]	Multiple[c]	1. Motorized brush saw 2. Power saw	$538	1. Vigorous sprouting of willow 2. Treatment damage to seedlings 3. Makes planting difficult
Sheep grazing	1. Reduce light competition	As soon as possible after seedlings harden off[d]	2–3[d]	1. Sheep 2. Cattle	$248	1. Potential for conifer damage if livestock are not carefully managed 2. Can only be used where willow is short (<1.5m)

[a] Based on average costs for the Kamloops and Nelson forest regions (B.C. Ministry of Forests 1999)
[b] Boyd et al. (1985)
[c] Hart and Comeau (1992)
[d] Newsome et al. (1995)

more abundant in the control than in the treatment, beforehand, and height differences tended to increase following glyphosate application (Table A1.3). Cover of shrubs and willow appeared to be unaffected by glyphosate. Sitka alder was also common on this site, and both its height and cover were reduced for at least 5 years by glyphosate. Cover of the herb layer was reduced for 1 year only.

Competition thresholds

A competition threshold for Douglas-fir stem diameter was not evident using willow cover as an index of neighbour competition. Douglas-fir diameter varied widely (3–10 cm) across all willow cover classes (range 0–100%). In contrast, Douglas-fir diameter declined sharply at CRH (CRH = (willow cover * willow modal height)/Douglas-fir height)

TABLE A1.2 *Average survival and growth responses of Douglas-fir seedlings to glyphosate on an unreplicated site in the Willow Complex*

	Survival (%)	Stem diameter (cm)	Height (cm)	Competetive status (%)		
				Free of vegetation	Threatened	Overtopped
Pre-treatment						
Glyphosate	100	2.6	84	14	80	6
Control	100	3.0	91	17	66	17
1 yr post-treatment						
Glyphosate	100	3.1	132	70	22	8
Control	100	3.5	151	28	50	22
3 yr post-treatment						
Glyphosate	100	4.1	173	75	22	3
Control	100	4.3	214	25	64	11
5 yr post-treatment						
Glyphosate	100	5.0	201	44	56	0
Control	100	5.5	247	6	88	6

TABLE A1.3 *Average cover and height of vegetation in the IDF Willow Complex before and after foliar glyphosate application to an unreplicated Douglas-fir plantation*

	All vegetation		Shrubs		Herbs		Willow		Sitka alder	
	Cover (%)	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height (cm)
Pre-treatment										
Glyphosate	77	84	26	110	57	30	7	232	7	172
Control	74	175	41	181	42	30	13	323	12	163
1 yr post-treatment										
Glyphosate	50	74	26	76	23	28	7	261	4	98
Control	76	129	45	200	41	33	11	254	21	188
3 yr post-treatment										
Glyphosate	75	42	36	70	42	34	7	92	4	43
Control	81	114	44	188	45	31	11	133	24	159
5 yr post-treatment										
Glyphosate	76	73	63	73	26	39	14	140	6	73
Control	82	157	70	157	26	35	17	215	29	157

index of 50 (range 0–90). However, only 4% of the trees were growing in neighbourhoods above the thresholds, and these trees would therefore benefit from selective brushing. All three trees above the threshold were control trees, whereas all treated trees and most control trees fell below the threshold (n = 72). Although brushing reduced willow below the CRH threshold, Douglas-fir diameter distributions remained unchanged from the control.

The linear regression of Douglas-fir diameter versus willow cover was not significant ($p>0.10$) (Table A1.4) because of the wide variability in Douglas-fir diameter across willow cover classes. In contrast, there was a significant, negative linear relationship between Douglas-fir diameter and CRH ($p<0.01$). However, the fit was poor (adjusted $r^2 = 0.08$) and the slope shallow ($\beta_1 = -0.011$), suggesting that the competitive effects of willow were of low importance and intensity. Fitting a negative exponential function to the diameter-CRH relationship did not improve the adjusted r^2.

Discussion

The following discussion of the *Willow* Complex is based mainly on information from published studies, and trends from our single, unreplicated PROBE study are included. The responses of Douglas-fir and the *Willow* Complex to brushing with glyphosate have been assessed on one PROBE site in the IDF zone over a period of 5 years; however, statistical analysis cannot be carried out until at least two more replicate sites have been established.

Conifer response

Although the *Willow* Complex has been identified as a competitor with young conifer seedlings in the southern interior (Kimmins and Comeau 1990), Haeussler et al. (1990) suggest that it is most problematic in northern SBS and BWBS ecosystems with a history of repeated fire. Burton's (1996) work in the CWHdm variant found that conifer seedlings grew at an average rate two-thirds of their potential when competing with Scouler's willow (*Salix scouleriana*). Studies in the southern interior indicate that conifers grow well among moderate amounts of mature willow, and outgrow its canopy within the free-growing window (Simard and Heineman 1996b; Simard, Heineman, and Youwe 1998). On our single site, survival of the 8-year-old Douglas-fir was not threatened by vegetation. Brushing with glyphosate did not improve seedling growth; instead it appears to have had a negative effect on growth during the 5-year monitoring period.

Plant community response

On our single PROBE site, glyphosate applied at 1.78 kg ai/ha had little effect on willow. Other recent studies in the Kamloops Forest Region similarly found glyphosate at 1.4–2.1 kg ai/ha to be ineffective at injuring willow (Simard and Heineman 1996b; Simard, Heineman, and Youwe 1998). These results contradict other studies, where glyphosate had been found to severely injure willow (Conard and Emmingham 1983; Boyd et al. 1985; Pollack et al. 1990). Boyd et al. (1985) found that willow was susceptible to glyphosate from May through October.

Willow may respond inconsistently to herbicides because of the wide variability that exists within and between species (Pollack et al. 1990). In addition, many types of insects and disease defoliate willow, which may affect its susceptibility to foliar herbicides (Haeussler et al. 1990). For example, willow leaf rust (*Melampsora epitea*) likely contributed to low glyphosate efficacy in one southern interior study (Simard and Heineman 1996b). On our site, the response of willow to glyphosate was apparently reduced by an infestation of ants that had caused dieback.

PROBE has not studied manual cutting of the *Willow* Complex, but other sources report it to be ineffective because willow sprouts so vigorously following cutting (Haeussler et al. 1990; Hart and Comeau 1992). Pollack et al. (1990) found that after upland willows were manually cut, each stump produced three to four sprouts that grew to a height of 74 cm within two seasons. Likewise, Simard and Heineman (1996b) found that manual cutting reduced willow height for only a single season, and had no effect on cover. In that study, cutting actually improved willow vigour by eliminating stems that were infected with willow leaf rust (*Melampsora epitea*). The response of willow to manual cutting can be variable, however; in another study in southern interior British Columbia, Simard, Heineman, and Youwe (1998) found that manual cutting reduced willow height and cover by approximately 85% for at least 3 years. After 9 years, abundance continued to reduced by more than 50%.

TABLE A.1.4 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting Douglas-fir stem diameter from the competition indices, willow cover, and CRH, in the Willow Complex in the IDF zone*

Site	Cover threshold (%)	p-value for linear regression predicting diameter from willow cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
17	None	0.18	50	$y = 5.455 - 0.011\ x$	0.08	0.01	$y = 5.466\ e^{(-0.0023*x)}$	0.09

[a] General form of linear equation is: $y = a + b\ x$, where y is Douglas-fir stem diameter, x is willow cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\ x$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (willow cover * willow modal height)/Douglas-fir total height.

[c] General form of non-linear equation is: $y = a\ e^{(b\ x)}$, where y is Douglas-fir stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

Effects of the community on resource availability

In southern interior British Columbia, mature willow seems to have little effect on resource availability to conifers, particularly where it occurs along with alder in a clumpy distribution on mesic or drier sites. Young willow sprouts may reduce light availability to conifer species, but there are no studies that examine the mechanisms of interspecific competition between juvenile willow and conifers. Willow is not known to directly benefit conifer seedlings, but decomposition of its nutrient-rich litter may improve nutrient availability to neighbouring conifers. Willow is an extremely important source of food and cover for wildlife, and also provides forage for cattle and sheep.

Competition thresholds

A competition threshold for stem diameter of 8-year-old Douglas-fir was not evident when willow cover was used as a competition index, but a threshold of 50 was apparent when the CRH index was used. Although stem diameter of Douglas-fir was sharply reduced above the CRH threshold, only 4% of trees were affected, indicating that growth of the plantation as a whole was unaffected by willow competition. Regressions relating Douglas-fir stem diameter to willow competition were either non-significant (willow cover) or had a very low coefficient of determination with shallow, negative slope (CRH). The poor regressions and lack of meaningful competition thresholds suggest that willow competition was neither an important nor severe constraint on Douglas-fir plantation performance (Weldon and Slauson 1986).

Douglas-fir stem diameter was highly variable across all willow cover classes and below the CRH threshold. The high variability in tree performance across competition indices suggests that the main growth constraints were unrelated to competition, and may include initial seedling size or vigour, genetics, environment, or biotic factors. This result suggests that reductions in willow abundance will not result in predictable responses of the Douglas-fir plantation. Our 5-year results showed that manual cutting reduced willow abundance to <40% cover and <40 CRH, but neither mean diameter nor diameter distributions of Douglas-fir appeared to improve.

There is no published information on competition thresholds for conifer seedlings growing among the *Willow* Complex. Simard, Heineman, and Youwe (1998) found that slight vigour reductions and leaf deformity of willow (35% control) (Expert Committee on Weeds 1983) resulting from glyphosate application improved lodgepole pine diameter growth. More severe treatments that reduced willow height and cover to a greater extent did not result in greater conifer growth responses. The results of our study, as well as those of Simard, Heineman, and Youwe (1998), suggest that brushing treatments in the *Willow* Complex are not necessary for adequate plantation performance. Brushing treatments that are performed should be light and select for the few trees growing inside dense willow clumps.

Effectiveness of treatment at meeting management objectives

In our study, the *Willow* Complex was brushed when Douglas-fir seedlings were 8 years old and less than 1 m tall. Surrounding vegetation was 2–3 m tall and not very dense. Brushing was prescribed primarily to help seedlings meet free-growing requirements as specified by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). Our site is required to have a target of 1000 (500 minimum) well-spaced seedlings at least 0.8 m tall and 100% as tall as surrounding vegetation, within 12–15 years of plantation establishment. Five years after brushing, when Douglas-fir seedlings were 13 years old, seedlings in both the treatment and control were taller, on average, than other vegetation. However, many continued to be threatened by surrounding vegetation, and their vigour had declined because of a plantation-wide aphid infestation. In general, seedlings in the treatment had better competitive status than those in the control, but that was likely the result of pre-treatment differences in vegetation abundance rather than the effects of brushing.

In two other southern interior studies, Engelmann spruce and lodgepole pine seedlings in untreated controls outgrew willow by ages 11 and 8 years, respectively, and were predicted to meet free-growing requirements well within the assessment window (Simard and Heineman 1996b; Simard, Heineman, and Youwe 1998).

Conclusions

Research from southern interior British Columbia suggests that conifer seedlings will outgrow the mature *Willow* Complex without brushing. In most southern interior plantations, willow is not abundant enough to impede survival, growth, or ability to meet free-growing obligations. On rich, moist sites, however, dense communities of juvenile willow may develop and negatively affect the performance of young conifers. Nevertheless, these site-specific competitive effects have never been quantified. Willow responds variably to glyphosate application, particularly when its vigour has been reduced by insects or disease. On our single PROBE site, and in two other southern interior studies, glyphosate had a minimal effect on the *Willow* Complex.

Management implications

1. Conifer seedlings tend to outgrow the *Willow* Complex without brushing intervention on mesic or drier sites in the southern interior.
2. Competition between willow and conifers is neither important nor severe on mesic or drier sites in the southern interior, and it does not appear to constrain conifer plantation performance.
3. Glyphosate has variable efficacy for controlling willow, particularly when it is affected by disease or insects.
4. Willow is extremely important to wildlife, and, as a result, unnecessary or overly severe brushing treatments should be avoided.

Introduction

This part of the Appendix describes first-year responses of newly planted lodgepole pine seedlings and the *Pinegrass* Complex to glyphosate spray on a single PROBE site in the MS biogeoclimatic zone. At present, only one site has been established for this treatment cell, so statistical analysis cannot be carried out and conclusions cannot be drawn. However, we discuss early trends in our results, and compare them with other studies reported in the literature. This part of the Appendix is formatted similarly to sections in the main body of the report, but less emphasis is placed on PROBE than on other, fully analyzed studies.

Description of the *Pinegrass* Complex

The *Pinegrass* Complex is dominated by pinegrass (*Calamagrostis rubescens*), but it may also include minor amounts of arctic lupine (*Lupinus arcticus*). In southern interior British Columbia, the *Pinegrass* Complex is most abundant on dry to fresh sites in the IDF and MS biogeoclimatic zones, and it also occurs in drier subzones of the ICH, SBS, and ESSF zones (Boateng and Comeau 1997e). Pinegrass occurs across a wide range of nutrient regimes (Haeussler and Coates 1986), and is common on sites with nitrogen deficiencies (Haeussler et al. 1990).

Development of the *Pinegrass* Complex

Although the shade tolerance of pinegrass is variable, its cover and root development often increase dramatically in response to harvesting, or in response to brushing treatments that remove broadleaves and shrubs from previously logged sites (Haeussler et al. 1990; Boateng and Comeau 1997e). Pinegrass also spreads as a result of the light to medium soil disturbance associated with harvesting, low-impact mechanical site preparation treatments, and low- to medium-intensity fires (Stickney 1986; Haeussler et al. 1990; Boateng and Comeau 1997e). Most pinegrass roots are found in the top 5 cm of soil, so severe disturbances to the surface soil horizon, such as those that occur during high-intensity fires (McLean 1979), are likely to set pinegrass back (Haeussler et al. 1990).

Interactions with conifer seedlings

Pinegrass produces abundant, shallow roots and rhizomes, and grows quickly in the early spring when water is most available (Nicholson 1989). These characteristics make it a strong competitor for soil water, particularly with conifer seedlings, which have their peak growth during mid-summer when soil water is most limiting (Nicholson 1989). Where pinegrass is well established prior to planting, it can be particularly limiting to seedling performance (Hauessler et al. 1990). On pinegrass-dominated sites, soil water content decreases as vegetation abundance increases (Petersen and Maxwell 1987), and site preparation techniques that remove pinegrass (scalping, ripping, and herbicide) can increase the amount of extractable water (Fleming et al. 1996).

Dense pinegrass cover can increase the incidence of summer frost damage to seedlings, particularly in flat areas or depressions where air mixing is limited. The grass layer insulates soil against warming during the day, and at night, traps cold, stagnant air at seedling height (Stathers 1989). One study on a pinegrass-dominated site in the southern interior showed that summer frost injury to Douglas-fir and Engelmann spruce seedlings could be reduced by scalping and ripping treatments. The exposed mineral soil warmed during the day and released heat during the night, offsetting the effects of frost (Black et al. 1991). Although treatments that remove forest floor materials can reduce the incidence of summer frost damage, they can also exacerbate nutrient deficiencies on sites that are already low in nitrogen. In the same study as Black et al. (1991), Hope (1991) found that scalping imposed foliar boron and nitrogen deficiencies on Douglas-fir in the IDF zone. Another study in the IDFdk1 showed that lodgepole pine seedlings performed better as a result of a spot chemical treatment than a mechanical patch treatment. It was concluded that retaining the forest floor and associated ectomycorrhizae was of nutritional benefit to seedlings in that study (Simard et al. 1998).

Seedling performance is frequently poor in the presence of the *Pinegrass* Complex, but identifying the primary limiting factor can be difficult. As Thorpe (1996) points out, when below-ground competition is intense, threshold vegetation cover can be deceptively low and the effects of soil water competition are often overlooked. On the other hand, where grass cover is heavier, it can mistakenly be assumed that competition for soil water is the primary limitation to seedling growth. For example, herbicide treatments were applied to relieve soil water competition on an IDF site near Lillooet, but growth of lodgepole pine seedlings did not improve. It was later noticed that seedlings growing on burned windrows were performing relatively well, and it was speculated that nutrient availability had been more limiting than moisture availability (Simard, Heineman, and Youwe 1998). Similarly, in another study on a pinegrass-dominated site in the MSdk, soil water competition was assumed to be limiting seedling performance. However, by age 11 years, Douglas-fir were exhibiting their best growth on convex areas of the cutblock that were drier than average. Those spots had considerable exposure of mineral soil, and it was speculated that low soil temperature may have been more limiting to seedlings than soil water competition (L. Bedford, pers. comm., 1998).

Importance to range and wildlife

Although pinegrass is not highly preferred by cattle, nor of particularly high nutritive value, its abundance in IDF forests makes it extremely valuable to the range resource. In the Douglas-fir zone (now known as the IDF zone), for instance, pinegrass accounts for over half the cattle forage production (McLean 1983). Cattle preference for pinegrass is low to medium in spring, and it declines as the grass matures. The crude protein content of pinegrass is medium in early summer, after which it declines. In contrast, crude fibre content is medium in early summer and increases later in the season (McLean 1979). In addition to its importance to cattle, pinegrass also provides year-round forage for Rocky Mountain elk (Kufeld 1973), and is an important early spring food for mule deer (Haeussler et al. 1990).

Management strategies for the timber and range resources are often in direct conflict on pinegrass-dominated sites. For instance, chemical brushing treatments applied to relieve soil water competition can decrease forage abundance, and forage enhancement treatments such as fertilization or seeding can increase competition to conifer seedlings. A conservative approach, with consultation between managers, should be taken in prescribing treatments for enhancement of either resource.

Common brushing treatments in the *Pinegrass* Complex

Chemical brushing treatments are often prescribed to reduce grass cover. The Expert Committee on Weeds (1987) recommends glyphosate application at 2.1 kg ai/ha for site preparation and 1.5–2.0 kg ai/ha for conifer release. Conard and Emmingham (1984) report that perennial grasses sustain 90–100% injury when glyphosate is applied at 1.12 kg ai/ha in summer and fall and 25–60% injury when it is applied in spring. Lloyd and Heineman (1994e) found that application of glyphosate at 2.1 kg ai/ha from mid-June to mid-July reduced pinegrass cover by 80–90% for 4 years, and that glyphosate at 1.4 kg ai/ha reduced cover by 75% for 3 years.

Hexazinone applied in spring can cause 60–90% injury to pinegrass, but results are variable (Conard and Emmingham 1984). Dimock et al. (1983) found that hexazinone applied to various perennial grasses in mid-May to mid-June resulted in about 70% control after 2 years, and about 50% control after 4 years. In another study, hexazinone applied at 1.1 kg ai/ha, as a ground spot treatment, reduced pinegrass cover by approximately 65% for 2–3 years. At 2.2 kg ai/ha, it reduced pinegrass cover by more than 80% for at least 3 years, and maintained a 40% reduction for 8 years (Simard, Perry et al. 1997). Common brushing treatments are described in Table A1.5.

Unreplicated Results

Ground foliar glyphosate application

Spot application of glyphosate to the *Pinegrass* Complex at Meadow Lake took place 1 month after lodgepole pine seedlings were planted. Pinegrass cover was reported to be approximately 40% at the time of treatment, but no pre-treatment measurements were carried out. The control plot was left untreated. The first assessment of vegetation took place approximately 2 months after glyphosate application, and the first assessment of conifers after approximately 3 months.

Description of the study site and treatment

The Meadow Lake site is located in the Kootenay Lake District of the Nelson Forest Region, approximately 20 km southeast of Yahk. It is in the Dry

TABLE A1.5 *Common brushing treatments applied to the Pinegrass Complex in the southern interior of British Columbia*

Treatment	Objective	Optimum timing	Suggested number of treatments	Tool	Average cost per ha[a]	Potential disadvantage
Foliar glyphosate spray (1.1–2.2 kg ai/ha)[b,c]	1. Reduce competition for soil moisture	As soon as possible after conifers are hardened off	1	1. Backpack sprayer	$700	1. Reduces range forage 2. Difficulties in obtaining herbicide permits
Hexazinone spray (1.1–2.2 kg ai/ha)[d]	1. Reduce competition for soil moisture	As soon as possible after conifers are hardened off	1	1. Spot gun	$700	1. Reduces range forage 2. Difficulties in obtaining herbicide permits

[a] Based on average costs for the Kamloops and Nelson forest regions (B.C. Ministry of Forests 1999)
[b] Expert Committee on Weeds (1987)
[c] Lloyd and Heineman (1994e)
[d] Simard et al. (1998)

Cool MS subzone (MSdk), at an elevation of 1450 m. The installation is located in mid-slope position, on a southwest-facing, 27% slope. Soil moisture regime is submesic (site series 04), and soils are silty clay-loam in texture. The block where PROBE is installed was clearcut in 1989–1990 and disc-trenched in 1990. It was planted with western larch in 1991 and fill-planted with lodgepole pine in 1996. In June 1996, glyphosate was applied as a spot treatment around the newly planted pine seedlings. It was applied with backpack sprayers at a rate of 1.02 kg ai/ha. Each conifer seedling was covered with a PVC cone while spraying took place in a 1.0-m radius.

Conifer response

Survival and vigour Lodgepole pine survival was negatively affected by glyphosate treatment on this block, even though individual seedlings were covered during spraying (Table A1.6). Spraying took place in June, when seedlings were highly susceptible to damage, and assessors noted curled tops and herbicide damage on 30% of seedlings soon afterward. One year later, 11% of seedlings had died in the treated plot, but there was no mortality in the untreated control.

Three months after glyphosate application, 97% of control seedlings were of moderate vigour, whereas, in the treated plot, 47% were moderate, 36% were of good vigour, and 16% were either poor or moribund. One year later, vigour was unchanged in the control, but had declined slightly in the treatment. The moribund seedlings had died and most seedlings that had been of good vigour were reduced to moderate vigour.

Growth One year after planting and chemical brushing, there was a trend towards slightly greater stem diameter and leader length (data not shown) among lodgepole pine seedlings in the treatment, but seedling height was similar in the treatment and control (Table A1.6). Three months after treatment, mean stem diameter across the treatment and control was 0.5 cm. One year later, it had increased to 0.7 cm in the treatment and 0.6 cm in the control. Seedling leaders were twice as long in the treatment (11 cm) as in the control (5 cm) 1 year after glyphosate treatment.

Competitive status The purpose of glyphosate application at the Meadow Lake site was to reduce competition for soil water, not for light. Overall vegetation height at the time of treatment was only about 45 cm. Glyphosate had little effect on the competitive status of pine seedlings, and, 1 year after brushing, the proportion of overtopped seedlings had increased similarly in both the treatment and control.

Vegetation response

Glyphosate had a surprisingly short-lived effect on the *Pinegrass* Complex at Meadow Lake. Two months after brushing, it was apparent that glyphosate had reduced cover, but not height, of all vegetation, the herb layer, and pinegrass (Table A1.7). Pinegrass dominated the vegetation at Meadow Lake, and its cover was reduced from 38% in the control to 22%. One year later, cover values for all vegetation, the herb layer, and pinegrass had recovered to within 3% of the control.

Competition thresholds

The pinegrass cover and CRH thresholds for lodgepole pine diameter were 40 and 68%, respectively,

TABLE A1.6 *Average survival and growth responses of lodgepole pine seedlings to spot application of glyphosate on an unreplicated site in the MS* Pinegrass *Complex*

	Survival (%)	Stem diameter (cm)	Height (cm)	Competitive status (%)		
				Free of vegetation	Threatened	Overtopped
Pre-treatment						
Glyphosate	100	0.5	22	19	17	64
Control	100	0.5	23	6	61	33
1 yr post-treatment						
Glyphosate	89	0.7	30	15	19	66
Control	100	0.6	29	6	11	83

TABLE A1.7 *Average cover and height of vegetation in the MS Pinegrass Complex before and after spot application of glyphosate in an unreplicated lodgepole pine plantation*

	All vegetation		Shrubs		Herbs		Pinegrass	
	Cover (%)	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height (cm)	Cover (%)	Height (cm)
2 months post-treatment								
Glyphosate	27	33	6	18	25	36	22	35
Control	42	35	6	20	39	35	38	35
1 yr post-treatment								
Glyphosate	32	46	6	20	28	46	25	46
Control	35	45	7	19	30	45	27	45

where CRH = (pinegrass cover * pinegrass modal height)/lodgepole pine height (Table A1.8). Lodgepole pine diameter was depressed by an average of 0.5 cm at both very high (>40%) and low (5–20%) pinegrass covers, and varied widely (0.3–1.7 cm) at intermediate (20–40%) covers (cover range 5–45%). Likewise, pine diameter declined sharply above the CRH threshold of 68, as well as when the CRH index dropped below 23 (CRH range 5–125). These results indicate that pine performance was suppressed both at low and very high levels of pinegrass.

Only 3–12% of trees were growing in pinegrass neighbourhoods above the thresholds, of which half were treated. These results suggest that glyphosate treatment was ineffective at releasing some of the suppressed trees. Conversely, all trees that were performing poorly at low pinegrass competition levels were treated trees, suggesting that treatment negatively affected their performance. At intermediate pinegrass levels, there was a wide distribution in lodgepole pine diameters in both the treated area and the control, but the largest trees tended to be treated trees. The small shift in diameter distribution at intermediate pinegrass covers is reflected in the tendency for larger average diameter in the treatment than in the control.

The linear regression of lodgepole pine diameter versus pinegrass cover was not significant ($p>0.10$) (Table A1.8) because of the wide variability in pine diameter across pinegrass cover classes. In contrast, there was a significant, negative linear relationship between pine diameter and CRH ($p = 0.01$). However, the fit was poor (adjusted $r^2 = 0.09$) and the slope shallow ($\beta_1 = -0.004$), suggesting that the competitive effects of pinegrass were of low importance and intensity. Fitting a negative exponential function to the diameter-CRH relationship did not improve the adjusted r^2.

Discussion

The following discussion of the *Pinegrass* Complex is based on information in the literature and first-year trends from our single, unreplicated PROBE study. A minimum of three replicate sites is required before statistical analysis can be carried out, making it impossible to draw conclusions from PROBE at this time.

Conifer response

One year after the June application of glyphosate at 1.02 kg ai/ha, survival of lodgepole pine seedlings was reduced from 100 to 89% in the treated plot. Mortality was attributed to herbicide damage, even though seedlings were covered at the time of treatment. The application of glyphosate for conifer release is not recommended until after seedlings are hardened-off (Lloyd and Heineman 1994e), but in this case, the objective was to reduce grass abundance around fill-planted lodgepole pine seedlings during the establishment period.

Surviving pine seedlings tended to increase in stem diameter but not total height in the treatment relative to the control. However, leaders were somewhat longer among treated seedlings. Seedling stem diameter commonly responds to release treatments more quickly than does height (Lanner 1985; Lanini and Radosevich 1986; Simard and Heineman 1996a, 1996c), and the growth response among these pine seedlings may not have been fully expressed within 1 year of treatment. The trend towards increased stem diameter suggests that, in spite of herbicide

TABLE A1.8 *Competition thresholds, regression equation parameter estimates, p-values, and adjusted r^2 values for predicting lodgepole pine stem diameter from the competition indices, pinegrass cover, and CRH, in the Pinegrass Complex in the MS zone*

Site	Cover threshold (%)	p-value for linear regression predicting diameter from pinegrass cover[a]	CRH threshold	Linear regression equation predicting diameter from CRH[b]	Adjusted r^2 for linear regression predicting diameter from CRH[b]	p-value for linear regression predicting diameter from CRH[b]	Non-linear regression equation predicting diameter from CRH[c]	Adjusted r^2 for non-linear regression predicting diameter from CRH[c]
127	40	0.58	68	$y = 0.835 - 0.004\ x$	0.09	0.01	$y = 0.864\ e^{(-0.0055 * x)}$	0.10

[a] General form of linear equation is: $y = a + b\ x$, where y is pine stem diameter, x is pinegrass cover, a is the intercept, and b is the slope.

[b] General form of linear equation is: $y = a + b\ x$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the slope. CRH = (pinegrass cover * pinegrass modal height)/pine total height.

[c] General form of non-linear equation is: $y = a\ e^{(b\ x)}$, where y is pine stem diameter, x is CRH, a is the intercept, and b is the asymptote at high CRH.

damage, seedling performance was slightly improved by the reduction in pinegrass competition.

Plant community response

Results from our single PROBE site suggest that glyphosate had a less severe impact on pinegrass than is generally described in the literature, even for such a low application rate (1.02 kg ai/ha). Pinegrass cover was reduced from 42 to 27% within 2 months of glyphosate application, but the following year it had recovered to within 3% of the control value. Similarly low application rates had a greater impact in other studies; glyphosate at 0.7 kg ai/ha in early July caused a 30–60% reduction in pinegrass cover over a period of 3 years (Lloyd and Heineman 1994e), and Conard and Emmingham (1984) suggest that glyphosate at 1.12 kg ai/ha, applied in summer, will result in 90–100% injury to perennial grasses. The lower than expected efficacy of glyphosate in our study is partly explained by the treatment radius being smaller (1.0 m) than the radius in which vegetation was assessed according to PROBE protocol (1.78 m).

Effects of the community on resource availability

A relatively minor and short-lived reduction in pinegrass abundance in this study appears to have slightly improved growth of lodgepole pine seedlings, suggesting that even a brief respite from soil water competition may have helped seedlings become established. Pinegrass is a well-known competitor for soil water (e.g., Petersen and Maxwell 1987; Nicholson 1989). One study that modelled conditions in the IDFdk subzone showed that, in the presence of pinegrass, the top 20 cm of soil rapidly dried to water potentials that were limiting to seedling growth. In comparison, where pinegrass was absent, the dry surface soil acted as a mulch, restricting water loss from lower horizons (Spittlehouse and Goldstein 1989).

Competition thresholds

The competition threshold for stem diameter of 6-year-old lodgepole pine was 40% pinegrass cover and 68 CRH (pinegrass cover * pinegrass modal height)/lodgepole pine height. Above the thresholds, competition from pinegrass appeared to be the most important factor limiting tree growth, setting the upper limit for pine diameter. However, only a small proportion (5–12%) of trees were growing in neighbourhoods above the thresholds, indicating that pinegrass competition was not constraining most trees in the population. In addition, regressions relating lodgepole pine diameter to pinegrass competition were either non-significant (pinegrass cover) or had a very low coefficient of determination with shallow negative slope (CRH). The poor regressions and high competition thresholds (i.e., trees above the thresholds represented only 5–12% of the plantation) suggest that pinegrass competition imposed neither an important nor severe constraint on lodgepole pine plantation performance (Weldon and Slauson 1986).

Below the competition thresholds, pine diameter was highly variable, suggesting that other factors were interacting with pinegrass to constrain pine growth potential. These factors could include genetic variability, microsite variability, initial size or vigour, or damage from herbicide, biotic, or abiotic agents. At the same time, however, the 7% largest trees were treated, and their faster growth rates may have resulted from reductions in pinegrass cover and increases in soil water availability. Trees growing among low levels of pinegrass (<20% cover or 23 CRH) had all been treated, but were performing poorly. Their poor performance may have resulted from herbicide injury or from negative conditions imposed by pinegrass removal. Some cover of pinegrass may be beneficial to seedlings, for example, by improving nutrient availability. This may occur through turnover of pinegrass litter, contributions to forest floor nutrient capital (Hope 1991), support of a healthy soil foodweb (Amaranthus and Perry 1987), or direct transfer of phosphorus through mycorrhizal linkages (Smith et al. 1998). Retention of pinegrass is also important to forage availability for cattle and wildlife.

There is no published information on competition thresholds for conifer seedlings growing among the *Pinegrass* Complex. However, we expect that competition thresholds vary considerably according to site conditions. For example, pinegrass competes for soil resources rather than for light, and thresholds are therefore likely to be lowest on the driest sites. Pinegrass develops an extensive root system, and its above-ground cover can sometimes be deceptively low on sites where soil water competition is the primary limitation to seedling growth (Thorpe 1996). Competition thresholds are also likely to vary according to seedling age and stage of development. A newly planted seedling is able to exploit only a small volume of soil, and is highly susceptible to any factor that decreases soil water availability. The survival and growth of newly planted seedlings is primarily affected by water uptake (Örlander et al. 1990), and good performance may require a period of 4 weeks following planting where soil water potentials do not drop below -0.1 MPa (Spittlehouse and Goldstein 1989).

Effectiveness of treatment at meeting management objectives

The purpose of spot-application of glyphosate to pinegrass at the Meadow Lake site was to reduce soil water competition in the neighbourhood of fill-planted lodgepole pine seedlings during the establishment period. Trends in both lodgepole pine and vegetation response suggest that glyphosate at 1.02 kg ai/ha met that objective without having an unnecessarily severe impact on range or wildlife resource values. Conifers showed signs of slightly improved growth within 1 year of treatment, even though pinegrass abundance recovered to control levels within the same time period. Brushing treatments are often applied to help meet free-growing requirements specified by the Forest Practices Code (B.C. Ministry of Forests 1995a) and Free Growing Guidelines (B.C. Ministry of Forests 2000). For the MSdk subzone, the Code specifies target stocking of 1200 (minimum 700) well-spaced conifers stems/ha. Lodgepole pine must be a minimum of 1.4 m tall and be 100% as tall as surrounding vegetation within 12–15 years of plantation establishment. Fill-planting was carried out on the Meadow Lake site to fulfill stocking requirements within the 7-year regeneration delay period. A free-growing assessment was not carried out because pine seedlings were only one year old at the time of treatment.

CONCLUSIONS

Trends from a single, unreplicated PROBE site appear to support other studies that show that a reduction in pinegrass abundance can improve seedling performance. However, on this site, the growth increases among treated pine were small, and were offset by an 11% increase in mortality due to herbicide damage. Glyphosate is often used as a site preparation treatment on sites where the *Pinegrass* Complex is well established, which eliminates the risk of herbicide damage to seedlings. However, on our site, glyphosate was applied as a spot treatment around fill-planted lodgepole pine seedlings. Mortality caused by the herbicide could reduce the likelihood of meeting the stocking requirement for free-growing.

MANAGEMENT IMPLICATIONS

1. Correct identification of limiting factors on dry sites is difficult because above-ground vegetation abundance may be very low. However, where soil water competition is correctly identified as the primary growth-limiting factor, brushing with glyphosate may reduce below-ground competition for this resource, and improve seedling performance.
2. For the purpose of improving soil water availability to newly planted seedlings, glyphosate is best applied as a site preparation treatment prior to planting.
3. If glyphosate is applied as a brushing treatment following planting, there will necessarily be a trade-off between treatment efficacy and conifer damage, since pinegrass is most susceptible from mid-June to mid-July, which is also when seedlings flush.
4. If pinegrass is treated with glyphosate, it is important to retain cover up to the lower threshold (20% cover) for optimal conifer growth and to preserve forage.

Appendix 2

Summary Statistics for Conifer and Vegetation Responses to Brushing Treatments on Single Replicate Sites

This section summarizes conifer and vegetation responses to brushing treatments that were replicated only once in a particular vegetation complex. It includes data from unreplicated treatments in all complexes that are presented in this report, except *Willow* and *Pinegrass* (see Appendix 1). The tables in this Appendix provide information about site characteristics (Table A2.1), conifer survival (Table A2.2), conifer growth (Table A2.3), vegetation cover (Table A2.4), and vegetation height (Table A2.5). Brief interpretations of the data are provided in Table A2.6. The trends presented in this Appendix are discussed in relation to other fully replicated treatments in the "Discussion" sections for each vegetation complex.

TABLE A2.1 *Site descriptions for single replicate sites*

Complex	Brushing treatment	Site	Location	MOF District	Subzone/site series	Years measured	Elevation (m)
Fireweed							
	Mulch mats	107	No Name Creek	Cranbrook	ESSFwm/01	5	1650
	Glyphosate	11	Chase Creek	Vernon	ESSFwk2/01	5	1400
	Manual	78	Longridge	Salmon Arm	ICHmw3	1	1060
	Manual	82	McIntyre	Vernon	ICHmw2	1	1400
	Manual	59	Tillis Landing	Salmon Arm	ICHmw2/04	1(3)	1075
	Glyphosate	63	Simard Road	Vernon	ICHmw2/01	1(3)	?
	Glyphosate	35	Kate Creek	Vernon	ICHmw2/01	5	1400
Fern							
	Manual	19	Legerwood Creek	Salmon Arm	ICHwk1/05	5	1125
Subalpine Herb							
	Grazing	14	Camp Creek	Clearwater	ESSFwc2/01	5	1650
Mixed Shrub							
	Manual	16	Mt. McLennan	Clearwater	ICHmw3/01	5	850
	Manual	61	Finn-Tum Tum	Clearwater	ICHvk1/04	1	760
	Glyphosate	103	Smith Creek	Golden	ICHwk1/01	5	1100
	Glyphosate	101	Bigmouth Creek	Revelstoke	ICHvk1/01	5	760
Ericaceous Shrub							
	Glyphosate	43	Craigellachie Creek	Salmon Arm	ESSFwc2/04	5	1480
	Glyphosate	120	Glenogle	Golden	ESSFwm/01	5	?
Dry Alder							
	Manual	10	Penticton Creek	Penticton	ESSFdc/01	5	1400
	Manual	85	McKay Creek	Lillooet	ESSFdv/01	1	1500
	Manual	8	Coalmont	Merritt	MSdm2/01	5	1450
	Manual	18	Nicoamen River	Lillooet	IDFdk2/05-01	5	1200
	Glyphosate	31	Crown Bench	Lillooet	MSxk/01	5	1400
Mixed Broadleaf-Shrub							
	Cut and spray	62	Mabel Lake	Vernon	ICHmw2/01	1	800
	Cut and spray	46	Burnyeat Creek	Vernon	ICHmw2/01	1	850
	Manual	5	Otter Creek	Clearwater	ICHmw3/05	5	760
	Manual	39	Raft River	Clearwater	ICHmw3/01	5	1070
	Manual; Triclopyr	69	Minnova Road	Kamloops	ICHmk1/01	1	1000
	Cut stump glyph	7	Larch Hills	Salmon Arm	ICHmw2/01	5	1070
Aspen							
	Manual	52	Chuck Creek	Clearwater	ICHmw3/01	3	800
	Manual	100	Susan Lake	Golden	ICHmw1/01	5	980
	Manual	77	Boone Creek	Salmon Arm	IDFdk2/01	1	1080
	Girdling	28	Mabel Creek	Kamloops	ICHmw3/05	5	950
	Girdling	74	Road 1221	Clearwater	ICHmw3/01	1	?
	Cut and Spray	40	Gollen Creek	Clearwater	ICHmw3	5	540
	Triclopyr	67	Spa Creek	Salmon Arm	MSdm2/01	1	1040
	Triclopyr	64	Dale Creek	Penticton	MSdm1/01	1	?

TABLE A2.1 *Continued*

Aspect and slope	Soil texture	Years since		Site prep treatment	Conifer		Conifer stocking	
		Logging	Site prep		Species	Age	Total	Well spaced
W 50%	SiL	4	4	Burn	Se	3	1370	1328
NW 28%	SiL	13	none	n/a	Pl	5	3569	1190
W 25%	L	5	?	Spot pile	Fd	1	2467	992
N 10%	SL	6	5	MSP	Sx	4	4667	1261
N 30%	SiL	3	2	MSP	Fd	1	1792	1090
N 30%	SL	3	2	Burn	Fd	1	1351	1140
W 30%	SL	6	5	Burn	Pl	3	1573	1136
S 30%	organic	17	2	Mech	Sx	1	772	742
NW 25%	SL	8	6	Burn	Se	0	2674	1200
N 30%	SL	20	3	MSP	Fd	1	1795	1036
NE 20%	SiCL	13	4	Burn	Cw	1	1681	839
NE 40%	SL	18	none	n/a	Fd	4	2003	450
SW 10%	S	2	2	Burn	Cw	1	1495	462
NE 40%	SL	12	3	MSP	Se	3	1781	1109
N 55%	SiL	11	none	n/a	Se	4	6386	1169
NW 30%	SL	21	10	MSP	Pl	9	5000	1200
N 35%	SL	5	none	n/a	Se	10	7683	1103
E 30%	SL	11	4	MSP	Pl	1	2406	1172
N 15%	SL	14	14	MSP	Sx	10	2820	1139
N 30%	SL	11	none	n/a	Pl	8	15709	1200
NW 30%	SL	5	4	Burn	Fd	2	1464	1200
SW 15%	SL	4	4	MSP	Pl	3	1540	1200
N 35%	SL	18	17	MSP	Sx	13	10,100	1194
NW 20%	SL	17	16	Burn	Sx	12	4703	1200
W 15%	SL	13	10	MSP	Fd	9	2013	1006
NW 25%	SiL	11	9	Burn	Cw	8	4775	1200
NW 15%	SiL	6	6	Burn	Fd	5	1195	703
SE 10-30%	SL	21	21	Burn	Fd	13	2359	781
E 15%	SiL	11	none	n/a	Pl	8	1761	825
S 30%	SL	8	8	Burn	Fd	5	888	862
NW 15%	SiCL	11	9	Burn	Fd	8	1994	978
NE 25%	SiL	5	5	Burn	Pl	2	1400	1139
SE 25%	L	8	8	Burn	Pl	6	1736	1064
W 20%	SL	11	9	MSP	Pl	4	1511	1103

TABLE A2.2 *Mean conifer survival for non-replicated PROBE treatments*

Complex	BGC Zone	Brushing treatment	Conifer species	PROBE Site	Pre-treatment(%)		1 yr post-trmt(%)		3 yr post-trmt (%)		5 yr post-trmt (%)	
					C	T	C	T	C	T	C	T
Fireweed												
	ESSF	Mulch mats	Se	107	100	100	100	100	94	94	89	94
	ESSF	Glyphosate	Pl	11	100	100	100	100	100	97	100	94
	ICH	Manual	Fd	78	100	100	100	97				
	ICH	Manual	Sx	82	100	100	100	100				
	ICH	Manual	Fd	59	100	100	100	94				
	ICH	Glyphosate	Fd	63	100	100	100	97				
	ICH	Glyphosate	Pl	35	100	100	97	100				
Fern												
	ICH	Manual	Sx	19	100	100	83	86	25	44	11	42
Subalpine Herb												
	ESSF	Grazing	Se	14	100	100	100	100	100	100	78	69
Mixed Shrub												
	ICH	Manual	Fd	16	100	100	100	100	100	100	100	100
	ICH	Manual	Cw	61	100	100	91	94				
	ICH	Glyphosate	Fd	103	100	100	100	100	97	97	92	97
	ICH	Glyphosate	Cw	101	100	100	97	89	97	89	94	83
Ericaceous Shrub												
	ESSF	Glyphosate	Se	43	100	100	100	89	94	86		
	ESSF	Glyphosate	Se	120	100	100	100	100	92	97		
Dry Alder												
	ESSF	Manual	Pl	10	100	100	100	100	100	100	100	100
	ESSF	Manual	Se	85	100	100	100	72				
	MS	Manual	Pl	8	100	100	64	94	61	94		
	IDF	Manual	Sx	18	100	100	100	100	100	100	100	100
	MS	Glyphosate	Pl	31	100	100	100	100	100	100	100	100
Mixed Broadleaf-Shrub												
	ICH	Cut and spray glyph	Fd	62	100	100	100	94				
	ICH	Cut and spray glyph	Pl	46	100	100	97	97				
	ICH	Manual	Sx	5	100	100	100	100	97	97	97	97
	ICH	Manual	Sx	39	100	100	100	100	100	100	100	100
	ICH	Manual	Fd	69	100	100	100	94				
	ICH	Triclopyr	Fd	69	100	100	100	100				
	ICH	Cut stump–glyph	Cw	7	100	100	100	100	100	100	92	97
Aspen												
	ICH	Manual	Fd	52	100	100	100	100	97	100		
	ICH	Manual	Fd	100	100	100	100	83	100	78	100	78
	IDF	Manual	Pl	77	100	100	94	100				
	ICH	Girdling	Fd	28	100	100	100	94	89	92	89	92
	ICH	Girdling	Fd	74	100	100	97	97				
	ICH	Cut and spray glyph	Pl	40	100	100	100	100	89	97	89	97
	MS	Triclopyr	Pl	67	100	100	100	100				
	MS	Triclopyr	Pl	64	100	100	100	100				

C = Control
T = Treated

TABLE A2.3 *Mean conifer growth measurements for non-replicated* PROBE *treatments*

Complex	BGC Zone	Brushing treatment	Conifer species	PROBE Site	Stem diameter (cm)							
					Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
					C	T	C	T	C	T	C	T
Fireweed												
	ESSF	Mulch mats	Se	107	0.63	0.71	0.74	0.71	1.12	1.33	1.93	2.38
	ESSF	Glyphosate	Pl	11	1.40	1.50	1.90	2.00	3.00	3.70	4.80	5.40
	ICH	Manual	Fd	78	0.66	0.63	1.13	1.03				
	ICH	Manual	Sx	82	2.30	2.42	2.96	3.19				
	ICH	Manual	Fd	59	0.60	0.60	1.20	1.30				
	ICH	Glyphosate	Fd	63	0.70	0.70	1.50	1.50				
	ICH	Glyphosate	Pl	35	1.00	1.00	1.80	2.30	3.40	3.80		
Fern												
	ICH	Manual	Sx	19	0.43	0.44	0.59	0.71	0.80	1.47	1.18	3.05
Subalpine Herb												
	ESSF	Grazing	Se	14	0.51	0.54	0.57	0.63	0.64	0.71	0.64	0.78
Mixed Shrub												
	ICH	Manual	Fd	16	1.07	1.08	1.53	1.61	2.16	2.46	3.10	3.38
	ICH	Manual	Cw	61	0.29	0.30	0.40	0.40				
	ICH	Glyphosate	Fd	103	1.04	0.94	1.71	1.47	3.70	2.11	3.93	3.03
	ICH	Glyphosate	Cw	101	0.68	0.82	0.90	0.99	1.40	1.80	1.92	2.53
Ericaceous Shrub												
	ESSF	Glyphosate	Se	43	0.55	0.52	0.75	0.61	0.96	0.88		
	ESSF	Glyphosate	Se	120	0.68	0.62	0.84	0.74	1.14	1.08		
Dry Alder												
	ESSF	Manual	Pl	10	3.90	3.90	4.80	4.90	6.58	6.37	6.89	7.58
	ESSF	Manual	Se	85	3.21	3.08	3.85	3.49				
	MS	Manual	Pl	8	0.40	0.40	0.50	0.70	0.60	1.60	0.66	2.36
	IDF	Manual	Sx	18	3.12	3.16	3.59	3.64	4.28	4.74	4.96	5.45
	MS	Glyphosate	Pl	31	2.88	2.65	3.44	3.29	4.50	4.36	5.45	5.22
Mixed Broadleaf-Shrub												
	ICH	Cut and spray glyph	Fd	62	1.12	0.84	1.59	1.37				
	ICH	Cut and spray glyph	Pl	46	1.88	1.85	3.78	4.68				
	ICH	Manual	Sx	5	4.75	4.99	5.22	5.66	6.20	7.10	7.12	8.07
	ICH	Manual	Sx	39	5.11	5.24	7.66	6.27	7.59	8.30	8.80	10.3
	ICH	Manual	Fd	69	4.69	3.08	5.69	4.56				
	ICH	Triclopyr	Fd	69	4.69	3.58	5.69	4.94				
	ICH	Cut stump–glyph	Cw	7	2.38	2.38	2.89	2.87	3.64	4.27	4.29	5.20
Aspen												
	ICH	Manual	Fd	52	1.28	1.14	1.51	1.64	1.85	2.17		
	ICH	Manual	Fd	100	6.14	4.98	7.48	6.33	8.70	9.30	10.68	9.87
	IDF	Manual	Pl	77	6.43	6.38	7.61	7.63				
	ICH	Girdling	Fd	28	2.05	1.78	2.38	2.38	3.63	4.49	3.70	5.41
	ICH	Girdling	Fd	74	2.23	2.80	2.89	4.07				
	ICH	Cut and spray glyph	Pl	40					2.52	3.13	5.48	6.97
	MS	Triclopyr	Pl	67	5.60	5.77	6.48	6.69				
	MS	Triclopyr	Pl	64	1.18	1.21	1.28	1.53				

C = Control
T = Treated

Height (cm)								Proportion of seedlings free-of-vegetation (%)							
Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment		Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
32	35	38	40	54	60	79	90	0	0	0	47	0	6	16	35
82	85	104	95	150	156	242	240	80	91	43	50	46	88	80	91
44	38	62	53					3	0	11	0				
85	91	116	122					75	69	58	86				
37	35	61	58					6	8	0	9				
43	41	71	61					3	14	3	29				
40	42	107	111	159	162			0	0	51	89	86	89		
24	26	31	36	48	62	62	106	0	0	17	14	75	56	0	80
27	29	35	38	37	39	40	44	0	14	3	8	0	0	0	0
46	46	87	88	142	156	197	228	3	6	3	11	6	6	3	6
19	18	25	29					0	0	0	0				
70	57	97	79	143	113	187	148	6	0	22	0	9	9	30	29
40	39	60	52	86	84	112	116	0	3	6	56	3	38	6	53
30	29	38	32	54	48			0	0	3	0	0	0		
43	40	58	51	74	64			0	0	0	19	0	11		
273	279	309	305	394	364	465	431	0	6	36	100	86	97	64	92
155	142	169	148					31	19	47	92				
18	20	21	33	32	75	45	115	0	0	0	0	0	3	0	3
105	115	142	149	177	186	204	216	25	8	28	58	17	22	11	11
162	149	193	170	268	231	340	308	17	8	25	42	75	69	88	86
70	53	90	64					11	0	42	67				
94	99	205	197					0	6	26	100				
183	189	281	297	357	385	421	478	3	17	0	33	6	47	6	49
209	214	279	284	350	362	435	437	6	19	3	75	0	44	0	31
224	154	316	201					14	17	14	76				
224	162	316	214					14	14	14	86				
197	185	207	202	250	265	311	336	0	0	0	39	0	54	0	31
85	69	102	80	126	108			0	0	0	0	0	0		
353	292	399	276	507	456	605	559	42	33	47	90	14	61	42	71
421	463	476	514					17	17	26	28				
96	97	114	121	169	201	186	224	28	6	19	29	31	64	22	58
119	123	162	183					0	0	0	20				
				192	209	323	320					25	79	31	60
294	294	361	349					25	33	44	80				
73	82	84	102					0	0	0	31				

TABLE A2.4 *Mean vegetation cover measurements for non-replicated* PROBE *treatments*

Complex	BGC Zone	Brushing treatment	PROBE site	Variable name	Variable # 1 — Cover (%)							
					Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
					C	T	C	T	C	T	C	T
Fireweed	ESSF	Mulch mats	107	All veg	87	89	80	82	74	70	67	70
	ESSF	Glyphosate	11	All veg	78	78	85	52	85	75	90	79
	ICH	Manual	78	All veg	63	66	58	67				
	ICH	Manual	82	All veg	67	69	69	61				
	ICH	Manual	59	All veg	54	39	63	45				
	ICH	Glyphosate	63	All veg	63	50	70	31				
	ICH	Glyphosate	35	All veg	69	60	74	52	81	76		
Fern												
	ICH	Manual	19	All veg	100	98	100	99	99	84		
Subalpine Herb												
	ESSF	Grazing	14	All veg	73	78	89	87	82	80		
Mixed Shrub												
	ICH	Manual	16	All veg	93	92	80	78	84	88	88	97
	ICH	Manual	61	All veg								
	ICH	Glyphosate	103	All veg								
	ICH	Glyphosate	101	All veg								
Ericaceous Shrub												
	ESSF	Glyphosate	43	All veg	97	97	98	79	97	94		
	ESSF	Glyphosate	120	All veg	72	78	72	12	72	47		
Dry Alder												
	ESSF	Manual	10	Alder	41	44	53	29	55	48	53	52
	ESSF	Manual	85	Alder	25	31	22	12				
	MS	Manual	8	Alder	47	47	56	23	63	51	63	52
	IDF	Manual	18	Alder	16	21	33	17	37	37	36	37
	MS	Glyphosate	31	Alder	21	26	27	12	28	12	32	22
Mixed Broadleaf-Shrub												
	ICH	Cut and spray glyph	62	Birch	8	5	12	3				
	ICH	Cut and spray glyph	46	Cottonwood	21	12	34	1				
	ICH	Manual	5	Birch	15	5	10	3	13	5	15	4
	ICH	Manual	39	Birch	9	19	12	9	13	9	18	15
	ICH	Manual	69	Birch	50	36	58	18				
	ICH	Triclopyr	69	Birch	25	18	58	1				
	ICH	Cut stump–glyph	7	Birch	39	39	13	1	37	1	56	3
Aspen												
	ICH	Manual	52	Aspen	28	36	36	26	31	25		
	ICH	Manual	100	Aspen	15	7	13	2	7	1	14	1
	IDF	Manual	77	Aspen	31	34	22	12				
	ICH	Girdling	28	Aspen	11	16	17	11	36	9	46	13
	ICH	Girdling	74	Aspen	31	19	44	14				
	ICH	Cut and spray glyph	40	Aspen					17	2	26	4
	MS	Triclopyr	67	Aspen	15	9	20	5				
	MS	Triclopyr	64	Aspen	44	41	40	10				

C = Control
T = Treated

TABLE A2.4 *Continued*

Variable name	Variable # 2 — Cover (%)								Variable name	Variable # 3 — Cover (%)							
	Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment			Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
	C	T	C	T	C	T	C	T		C	T	C	T	C	T	C	T
Herbs	72	73	61	54	60	46	57	49	Fireweed	71	68	57	51	50	39	46	35
Herbs	73	72	78	48	75	69	76	74	Fireweed	33	35	45	3	51	11	55	14
Herbs	52	52	44	51					Fireweed	29	26	25	26				
Herbs	55	58	56	42					Fireweed	18	29	17	6				
Herbs	46	35	50	36					Fireweed	31	28	29	24				
Herbs	43	28	43	19					Fireweed	34	27	38	16				
Herbs	63	49	69	37	73	60			Fireweed	35	30	31	5	26	7		
Herbs	88	93	95	100	95	81	87	74	Bracken	15	44	16	43	26	17	23	12
Herbs	47	59	46	55	49	53			Valerian	9	6	5	7	2	6		
Shrubs	32	31	52	59	63	71	79	94	Herbs	66	65	35	26	38	33	24	28
Shrubs	51	42	56	47					Herbs	39	49	52	59				
Shrubs	64	42	46	36	59	53	55	57	Herbs	40	63	45	52	36	43	39	41
Shrubs	29	40	31	14	31	34			Herbs	56	30	64	42	60	42	57	41
Shrubs	71	65	66	25	71	35			Herbs	84	87	60	69	63	83		
Shrubs	63	68	49	7	54	13			Herbs	29	48	24	6	24	35		
Fireweed									Herbs	18	11	12	13	11	24	15	11
Fireweed	31	19	20	16					Herbs	31	19	21	16				
Fireweed	11	9	21	21	24	23	13	11	Herbs	38	35	36	41	30	35	29	28
Fireweed	7	10	14	13	8	13	8	6	Herbs	41	43	43	37	47	39	33	34
Fireweed	8	9	10	3	8	3	7	5	Herbs	10	11	15	12	14	15	15	18
Thimbleb'ry	5	6	8	1					Herbs	23	12	20	12				
Shrubs	37	26	35	10					Herbs	31	32	29	19				
Thimbleb'ry	3	5	2	5	2	6	3	10	Herbs	11	16	7	9	5	15	4	19
Shrubs	33	23	30	28	43	36	41	46	Herbs	31	45	31	27	52	46	43	41
Thimbleb'ry	25	13	39	22					Herbs	24	24	19	38				
Thimbleb'ry	25	18	39	23					Herbs	24	33	19	39				
Thimbleb'ry	28	28	43	36	66	50	49	39	Herbs	3	6	1	2	6	10	9	8
Herbs	32	34	33	40	23	19			Shrubs	46	22	41	26	51	32		
Herbs	29	23	26	28	21	20	17	33	Shrubs	57	69	69	47	61	39	65	58
Herbs	63	54	35	38					Shrubs	65	64	53	42				
Herbs	6	15	16	39	12	31	no data		Shrubs	17	17	32	22	52	58	65	72
Herbs	40	59	21	51					Shrubs	35	33	54	56				
Herbs					7	6	9	14	Shrubs					49	42	50	45
Herbs	12	14	12	20					Shrubs	51	53	57	49				
Herbs	68	51	57	57					Shrubs	50	51	55	47				

TABLE A2.5 *Mean vegetation height measurements for non-replicated PROBE treatments*

					Variable # 1—Height (cm)							
					Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
Complex	BGC Zone	Brushing treatment	PROBE Site	Variable name	C	T	C	T	C	T	C	T
Fireweed	ESSF	Mulch mats	107	All veg	124	113	63	57	83	66	74	67
	ESSF	Glyphosate	11	All veg	63	67	103	26	137	57	150	100
	ICH	Manual	78	All veg	91	94	121	118				
	ICH	Manual	82	All veg	76	85	96	72				
	ICH	Manual	59	All veg	68	62	93	78				
	ICH	Glyphosate	63	All veg	92	87	113	72				
	ICH	Glyphosate	35	All veg	42	46	53	26	83	56		
Fern												
	ICH	Manual	19	All veg	147	157	163	147	171	64	200	69
Subalpine Herb												
	ESSF	Grazing	14	All veg	38	35	60	24	42	33	90	81
Ericaceous Shrub												
	ESSF	Glyphosate	43	All veg	126	120	118	70	123	109		
	ESSF	Glyphosate	120	All veg	75	74	97	95	109	47		
Dry Alder												
	ESSF	Manual	10	Alder	190	199	193	65	206	147	235	176
	ESSF	Manual	85	Alder	261	249	264	83				
	MS	Manual	8	Alder	280	280	309	120	331	180	346	219
	IDF	Manual	18	Alder	190	215	214	92	186	155	198	166
	MS	Glyphosate	31	Alder	168	184	184	153	223	177	229	188
Aspen												
	ICH	Manual	52	Aspen	301	365	353	115	490	173		
	ICH	Manual	100	Aspen	495	383	462	47	619	93	666	83
	IDF	Manual	77	Aspen	699	799	848	855				
	ICH	Girdling	28	Aspen	372	401	340	373	700	741	735	600
	ICH	Girdling	74	Aspen	337	326	323	281				
	ICH	Cut and spray glyph	40	Aspen					334	78	468	121
	MS	Triclopyr	67	Aspen	310	329	398	310				
	MS	Triclopyr	64	Aspen	677	516	760	310				
Mixed Shrub												
	ICH	Manual	16	All veg	111	163	102	74	135	111	188	204
	ICH	Manual	61	All veg	90	97	124	113				
	ICH	Glyphosate	103	All veg	149	140	109	110	94	117	124	160
	ICH	Glyphosate	101	All veg	75	80	105	57	115	70	121	94
Mixed Broadleaf-Shrub												
	ICH	Cut and spray glyph	62	Birch	249	299	257	114				
	ICH	Cut and spray glyph	46	Cottonw'd	119	112	164	100				
	ICH	Manual	5	Birch	399	380	488	133	543	286	729	326
	ICH	Manual	39	Birch	354	407	545	113	462	168	490	245
	ICH	Manual	69	Birch	281	310	415	173				
	ICH	Triclopyr	69	Birch	281	358	415	246				
	ICH	Cut stump–glyph	7	Birch	478	415	526	104	692	212	816	317

C = Control
T = Treated

TABLE A2.5 *Continued*

	Variable # 2 — Height (cm)									Variable # 3 — Height (cm)							
	Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment			Pre-treatment		1 yr post-treatment		3 yr post-treatment		5 yr post-treatment	
Variable name	C	T	C	T	C	T	C	T	Variable name	C	T	C	T	C	T	C	T
Herbs	146	122	63	59	86	71	75	67	Fireweed	153	140	57	51	84	70	79	69
Herbs	63	67	102	18	133	50	149	87	Fireweed	93	97	115	26	135	122	149	138
Herbs	88	89	119	107					Fireweed	99	99	132	135				
Herbs	74	85	96	72					Fireweed	81	83	88	62				
Herbs	68	61	88	84					Fireweed	82	60	120	92				
Herbs	94	87	119	79					Fireweed	95	88	128	79				
Herbs	39	46	48	16	78	53			Fireweed	71	70	85	30	88	62		
Herbs	147	156	159	149	171	59	168	65	Bracken	133	149	119	138	154	88	144	88
Herbs	37	36	58	13	42	31	90	81	Valerian	36	32	56	12	41	35	91	83
Shrubs	128	119	119	101	123	108			Herbs	57	73	55	45	47	71		
Shrubs	78	81	99	102	112	69			Herbs	25	23	67	33	63	33		
									Herbs	20	19	26	31	31	36	39	32
Fireweed	117	99	115	100					Herbs	117	99	115	101				
Fireweed	108	101	113	102	120	96	104	114	Herbs	46	49	77	73	30	35	81	90
Fireweed	94	117	70	76	102	108	81	73	Herbs	35	36	30	34	42	53	41	45
Fireweed	49	56	55	20	73	42	55	46	Herbs	54	55	49	20	65	24	54	29
Herbs	110	109	109	89	76	84			Shrubs	82	62	84	43	96	71		
Herbs	50	34	16	10	24	12	18	20	Shrubs	239	300	335	89	194	82	107	68
Herbs	20	24	19	24					Shrubs	122	221	126	118				
Herbs	85	72	54	61	64	64	no data		Shrubs	49	134	49	52	60	108	60	108
Herbs	40	38	40	36					Shrubs	63	58	71	80				
Herbs					78	70	65	42	Shrubs					47	51	49	55
Herbs	53	41	57	56					Shrubs	56	60	59	64				
Herbs	55	43	60	59					Shrubs	152	123	159	101				
Shrubs	150	163	103	74	126	111	167	197	Herbs	53	66	41	36	36	20	24	16
Shrubs	85	87	116	105					Herbs	101	101	126	114				
Shrubs	165	152	104	101	98	118	100	136	Herbs	78	100	56	88	48	86	55	90
Shrubs	61	79	70	47	69	74	81	86	Herbs	75	75	106	48	114	55	132	89
Thimbleb'ry	71	68	58	35					Herbs	70	73	37	51				
Shrubs	55	57	57	44					Herbs	99	93	101	43				
Thimbleb'ry	28	43	43	54	41	54	53	69	Herbs	86	72	99	84	55	34	61	35
Shrubs	69	67	67	89	109	94	93	122	Herbs	87	94	99	80	77	63	12	21
Thimbleb'ry	55	54	78	58					Herbs	66	51	93	80				
Thimbleb'ry	55	60	78	72					Herbs	66	75	93	83				
Thimbleb'ry	115	107	124	92	161	136	137	152	Herbs	16	21	23	57	121	165	101	171

TABLE A2.6 *Summary of responses for non-replicated PROBE treatments*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Fireweed	ESSF	Mulch mats	Se	107	*Arbortec* brush blankets were applied to 3-year-old Engelmann spruce seedlings growing among a dense *Fireweed* Complex. Five years after the blankets were applied, survival was 94% in the treatment, compared to 89% in the control. The causes of mortality were not identified. Treated seedlings had larger stem diameters than control seedlings within 3 years of brush blanket application, and were also gaining in height by year 5. The brush blankets freed about half the treated seedlings from surrounding vegetation in the first-year assessment, but by year 3, most were again overtopped. However, by year 5 seedlings were beginning to outgrow the brush, with 16% of control seedlings and 35% of treated seedlings being free of vegetation. The brush blankets reduced the cover of both the herb layer and fireweed during the 5-year assessment period, but had no effect on height (probably because the brush blankets occupied only a fraction of the plot radius).	Unpublished
Fireweed	ESSF	Glyphosate	Pl	11	Glyphosate at 1.78 kg ai/ha significantly reduced abundance of the *Fireweed* Complex for 3–5 years, but had no effect on growth or survival of lodgepole pine seedlings. Seedlings were performing well in both glyphosate treatment and control, and were well above vegetation in both treatments.	Mather and Simard 1998b
Fireweed	ICH	Manual	Fd	59	Fireweed cover was reduced by 5% in the first year after manual cutting, but otherwise, vegetation was unaffected by treatment. Stem diameter of Douglas-fir seedlings increased in year 1, but only by 0.1 cm (1.2 versus 1.3 cm). There was no height response. Survival was high in both treatment and control in year 1, and vigour improved regardless of treatment.	Mather and Simard 1998g
Fireweed	ICH	Manual	Fd	78	One year after manual treatment of the *Fireweed* Complex, survival of the 3-year-old seedlings was high in both treatment and control. About 85% of seedlings were of moderate to good vigour at the start of the trial, and this had not changed one year after treatment. Manual cutting had no effect on Douglas-fir stem diameter or height, and did not reduce the percentage of overtopped trees. Manual cutting in late summer did not reduce cover or height of fireweed in the following season.	Unpublished
Fireweed	ICH	Manual	Sx	82	One year after manual cutting of the *Fireweed* Complex, spruce seedling survival was 100% in both the treatment and control and there were no differences in seedling stem diameter or height. Cover and height of all vegetation, the herb layer, and fireweed had been reduced in comparison to the control, and overtopping was reduced.	Unpublished

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Fireweed	ICH	Glyphosate	Fd	63	One year after application of glyphosate at 1.78 kg ai/ha, cover of the *Fireweed* Complex was less than half control levels, and height was reduced by 20–30%. There were no positive growth responses among Douglas-fir seedlings in year 1, however. Height was negatively affected by treatment and stem diameter was unchanged. Survival was high in both treatment and control, but vigour had dropped slightly in both.	Mather and Simard 1998i
Fireweed	ICH	Glyphosate	Pl	35	Glyphosate at 1.78 kg ai/ha reduced height and cover of the herb layer and fireweed for at least 3 years. Lodgepole pine stem diameter increased substantially within 1 year of treatment (2.3 versus 1.8 cm), but height was unaffected. However, most seedlings in both treatment and control were above surrounding vegetation by year 3. Survival was high in both treatment and control, and vigour was moderate to good in both.	Mather and Simard 1997b
Fern	ICH	Manual	Sx	19	A 25-cm-tall spruce plantation buried under dense, lush vegetation received 14 manual brushing treatments in 5 consecutive years. Each treatment greatly reduced vegetation abundance, but the plant community consistently recovered in a short period of time. After 5 years, survival in the control was only 11%, and half the remaining seedlings were of poor vigour. Survival was better in the treatment, but it was still too low (42%) to meet minimum stocking requirements. However, surviving seedlings in the treated area were generally healthy and had much better growth than those in the control. Vegetation competition caused most mortality in both plots, but about 15% of seedlings in the brushed area died because they were cut during treatment.	Mather and Simard 1997f (and unpublished fifth-year data)
Subalpine Herb	ESSF	Grazing	Se	14	Five years after sheep grazing, Engelmann spruce stem diameter was larger among treated seedlings, but growth was slow in both treatment and control. Height of the 5-year-old seedlings averaged 42 cm, and was similar in the treatment and control. Seedling survival and vigour had declined since grazing. By year 5, survival was 78% in the control and 69% in the treatment, and the majority of surviving seedlings were of poor vigour. Grazing reduced height and cover of all vegetation, the herb layer, and Sitka valerian for 3–5 years, but had no effect on shrubs.	Mather and Simard 1997d

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Mixed Shrub	ICH	Manual	Fd	16	A single manual cutting treatment was applied in August in a 1-m radius around 4-year-old Douglas-fir seedlings growing under a dense mixture of thimbleberry, willow, Douglas maple, red osier dogwood, and black twinberry. Five years after brushing, Douglas-fir height was 16% (31 cm) greater in the brushed area than in the control, but diameter remained similar. Survival was 100% in both plots but there were more poor vigour trees in the control (17%) than in the brushed area (0%). After 5 years, the competitive status of Douglas-fir was the same in the treated area and control; only 5% of trees were free of vegetation and 20% were overtopped. The covers of thimbleberry, red osier dogwood, black twin-berry, and willow were similar before and 1 year after treatment, but the cover of Douglas maple was reduced for 2 years. Shrub height fully recovered by the third year after cutting, and the heights of Douglas maple, red osier dogwood, and black twinberry were greater in the treated area than in the control after 3 years.	Mather and Simard 1997c
Mixed Shrub	ICH	Manual	Cw	61	A single manual cutting treatment was applied in July in a 1-m radius around cedar that had just been planted under a vegetation community dominated by thimbleberry, raspberry, lady fern, and fireweed. The vegetation community recovered in 1 year. Height growth was slightly (4 cm) greater in the treated area than in the control 1 year after brushing, but there was no response in diameter. Cedar vigour declined in both plots, but slightly more so in the control. However, few trees in either plot were in poor condition or dead 1 year after brushing, in spite of the dense vegetation. Survival of cedar was 94% in the brushed area and 91% in the control; mortality was caused by vegetation competition. All cedar were overtopped before and 1 year after brushing, but the trees were gradually outgrowing the vegetation.	Mather and Simard 1998h
Mixed Shrub	ICH	Glyphosate	Fd	103	Broadcast glyphosate spray at 2.1 kg ai/ha in August had very little impact on a vegetation community dominated by fireweed and red raspberry. The plants experienced some curling of leaves in the year herbicide was applied, but 1 year after treatment, vegetation abundance had not been reduced. The reason for poor efficacy of the treatment is unknown. Five years after treatment, growth, vigour, and survival (93%) were equally good in the brushed area and in the control. Mortality was caused by a variety of agents including *Armillaria ostoyae*, snow breakage, hare browsing, and poor planting quality, but not including vegetation competition. Five years after treatment, competitive status was the same in both plots: 30% of the 9-year-old Douglas-fir were free of vegetation, 50% were overtopped, and trees averaged 75% of the vegetation height. Treated and untreated trees were gradually outgrowing the vegetation.	Unpublished

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Mixed Shrub	ICH	Glyphosate	Cw	101	Spot glyphosate application at 2.1 kg ai/ha in August severely set back a vegetation community dominated by thimbleberry, raspberry, lady fern, and fireweed. The herbicide severely reduced the cover of total shrubs and each of the dominant species 1 year after treatment, but the cover of total herbs recovered in 1 year. Red raspberry and fireweed regained pre-treatment covers within 3 years, but the covers of lady fern and thimbleberry were severely set back for 5 years. Heights of the four dominant species nearly recovered in 5 years. Five years after herbicide treatment, cedar was 32% (0.6 cm) larger in diameter in the herbicided area than in the control, but height was similar. Survival was better in the control (94%) than the herbicided area (83%); mortality was caused by a variety of agents including drought, flooding, and rodent browsing. Vegetation competition did not contribute to mortality even though untreated trees were growing in dense vegetation throughout the measurement period. Five years after treatment, vigour was similar in both plots and all surviving trees were healthy. Before brushing, all seedlings were overtopped, but after 5 years, 53% of treated trees were free of vegetation and 27% were overtopped. In the control, only 6% were free of vegetation and 65% were overtopped.	Unpublished
Ericaceous Shrub	ESSF	Glyphosate	Se	43	Glyphosate at 2.1 kg ai/ha had a slightly negative effect on survival of Engelmann spruce (94 versus 86%) and no effect on growth. Height and cover of shrubs in the *Ericaceous Shrub* Complex were reduced for at least 3 years. Height and cover of herbs increased during that time, likely in response to increased light.	Mather and Simard 1988o
Ericaceous Shrub	ESSF	Glyphosate	Se	120	Three years after treatment of the *Ericaceous Shrub* Complex with glyphosate at 2.0 kg ai/ha, Engelmann spruce survival was above 90% in both treatment and control, but there were no positive effects on seedling growth. Seedling stem diameter was unaffected by treatment, but height was reduced in comparison to the control in both year 1 and year 3. Height and cover of "all vegetation" and of the shrub layer were reduced by glyphosate for at least 3 years, whereas herb cover was reduced by treatment for 1 year, but by year 3 it had recovered and surpassed control levels.	Unpublished
Dry Alder	ESSF	Manual	Pl	10	Pine diameter increased and height decreased slightly following manual cutting, but the treatment was not required to obtain excellent survival and a healthy plantation. After 5 years, most of the treated trees and two-thirds of the untreated trees were free of vegetation. Alder in the treated area had the same cover (53%) and three-quarters the height of alder in the control 3 years after manual cutting.	Mather and Simard 1998c

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Dry Alder	ESSF	Manual	Se	85	Spruce diameter and height did not respond in the first year following manual cutting. Survival was 100% in the control, but only 72% in the brushed area due to cutting of PROBE crop trees during spacing. One year after brushing, 92% of the treated seedlings were free of vegetation. Untreated seedlings did not start to outgrow the alder in the 1-year measurement period.	Unpublished
Dry Alder	MS	Manual	Pl	8	Pine that was planted under a dense alder canopy benefited greatly from a manual cutting treatment. The treatment greatly improved survival and helped prevent a decline in pine vigour. Height and diameter growth were dramatically greater in the manually cut area than in the control, and growth rates continually improved from 1 to 5 years after brushing, in spite of the rapid regrowth of alder. Alder regrew rapidly in the first 3 years after cutting, but increased little in height or cover between year 3 and 5. Alder sprouts were 63% as tall and had 80% the cover of untreated alder 5 years after treatment.	Mather and Simard 1998d
Dry Alder	IDF	Manual	Sx	18	Spruce diameter increased slightly, but height did not respond in the first 5 years after manual cutting of alder and willow. The treatment was not required to obtain excellent survival and a healthy plantation. Few spruce were free of vegetation 5 years after treatment because vigorous alder sprouts caught up to the relatively slow-growing conifers. Alder cover was the same (37%) in the brushed area and control 3 years after brushing and the height of alder sprouts reached the height of uncut alder after 5 years. Willow cover was not reduced by brushing, but height was reduced for 3 years.	Mather and Simard 1997e
Dry Alder	MS	Glyphosate	Pl	31	Pine growth and vigour were unaffected by the herbicide treatment, which severely set alder back for the 5-year measurement period. Beginning 3 years after glyphosate application, most of the treated and untreated pine were free of vegetation.	Mather and Simard 1998m
Mixed Broadleaf-Shrub	ICH	Cut, spray glyphosate	Fd	62	Glyphosate application to a light cover of birch killed the hardwoods and resulted in a slight increase in Douglas-fir diameter and a slight decrease in height growth 1 year after treatment. Douglas-fir vigour decreased in both the treated area and control, but survival was good (100% in the control and 94% in the treated area). Mortality was attributed to poor planting. Before treatment, 81% of Douglas-fir were overtopped and only 5% were free of vegetation. One year afterward, two-thirds of treated trees and half the untreated trees were free of vegetation, and only 12% of treated trees and 30% of control trees were still overtopped. The untreated trees were quickly outgrowing the vegetation.	Mather and Simard 1998j

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Mixed Broadleaf-Shrub	ICH	Cut, spray glyphosate	Pl	46	Cottonwood and birch were cut in both the treated area and control, then the following year sprouts were sprayed with glyphosate in the treated area only. One year after herbicide application, average pine diameter was 24% (0.9 cm) greater in the treated area than in the control, but leader growth of treated trees was reduced slightly. Pine vigour was not initially affected by the herbicide treatment, and survival was 97% in both plots. Mortality was caused by *Armillaria.* The treatment immediately created a stand that was free of vegetation, but untreated pine were naturally outgrowing the broadleaves.	Mather and Simard 1998k
Mixed Broadleaf-Shrub	ICH	Manual	Sx	5, 39	Three years after brushing, average spruce diameter was 9–14% (0.7–0.9 cm) greater in the treated areas than in the controls, but height growth was unaffected. One site was monitored for 5 years, and after this longer measurement period, total height was 14% (57 cm) greater in the brushed area than in the control. On one site, survival was 100% in both plots, and on the other site *Armillaria* caused 3% mortality in both plots. On one site, vigour was unaffected by treatment, whereas on the other, weevil damage resulted in greater loss of vigour in the treated area than in the control. Three to 5 years after brushing, half of the treated spruce (and 3% of the untreated spruce) were free of vegetation. The untreated spruce were not outgrowing the broadleaves.	Mather and Simard 1998f (PROBE 5) Mather and Simard 1998p (PROBE 39)
Mixed Broadleaf-Shrub	ICH	1) Manual 2) Triclopyr	Fd	69	Triclopyr application killed all treated broadleaf trees, and no resprouting occurred in the first year after brushing. Manual cutting resulted in vigorous resprouting. Neither treatment resulted in an increase in Douglas-fir diameter or height 1 year after brushing, but vigour in both treated plots improved while vigour in the control remained constant. One year after brushing, most (80–85%) Douglas-fir in both brushed plots were free of vegetation, while the competitive status of Douglas-fir in the control remained constant (14% were free of vegetation and 25–30% were overtopped).	Unpublished

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Mixed Broadleaf-Shrub	ICH	Cut stump-glyphosate	Cw	7	A heavy birch canopy was removed by cutting, and application of glyphosate to the stumps eliminated resprouting. Five years after brushing, average cedar diameter was 21% (0.9 cm) bigger and leader growth was 40% greater in the treated area than in the control, but there was no difference in total height between the two plots. Survival after 5 years was 97% in the treated area and 92% in the control; mortality was due to a variety of factors unrelated to vegetation competition. Cedar vigour was not affected by the treatment; both treated and untreated stands were healthy. Five years after brushing, 31% of treated cedar (and 0% of untreated cedar) were free of vegetation, and 35% of treated trees and 100% of control trees were overtopped. The untreated cedar was not outgrowing the birch.	Mather and Simard 1998a
Aspen	ICH	Manual	Fd	52, 100	Manual cutting was not required to maintain excellent survival of Douglas-fir, but on one site, treatment damage caused 22% mortality. On one site, vigour was the same in the brushed area and control 5 years after treatment, but in the other site 40% of untreated trees declined from moderate to poor vigour while most treated trees stayed healthy. On both sites, Douglas-fir height and diameter increased moderately by the third year after brushing. On one site, aspen abundance was greatly reduced for 5 years, but on the other the species rapidly invaded and reached the same cover as the control after 5 years. At the site where Dougas-fir was tall (3 m) at the time of brushing, 71% of treated trees and 42% of control trees was free of vegetation 5 years after brushing. At the other site, where Douglas-fir was 0.7 m tall at the time of brushing, none of the treated or untreated trees were free of vegetation 3 years after brushing. At both sites, herb cover increased slightly after treatment. At one site, the increase in herbs was present only in the first year after brushing, whereas at the other site, the increase did not appear until 5 years after brushing.	Mather and Simard 1997a (PROBE 52) Unpublished (PROBE 100)

TABLE A2.6 *Continued*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Aspen	IDF	Manual	Pl	77	Manual cutting (400 aspen stems/ha retained) had no effect on aspen height, but reduced its cover to 12% (versus 22% in the control) 1 year after brushing. The reduction in aspen abundance had virtually no effect on competitive status of pine; 1 year after brushing, 27% of pine were free of vegetation and about 60% were overtopped in both the treatment and control. Brushing resulted in no initial response in height or diameter growth of pine. Survival was 100% in the brushed area and 94% in the control; mortality resulted from girdling of stems by rodents. Average vigour remained relatively constant in both the manually cut area and control, but the percentage of good-vigour trees increased slightly more in the brushed area (19%) than in the control (8%), whereas the precentage of poor-vigour trees increased slightly more in the brushed area than in the control (7 versus 3%). Herb cover increased slightly and shrub height and cover decreased after treatment.	Unpublished
Aspen	ICH	Girdling	Fd	28	Girdling of aspen (650 aspen stems/ha retained) increased the height and diameter growth of Douglas-fir and improved the vigour of the stand. Survival was similar in the treated area (92%) and control (89%) 5 years after treatment, but one-third of untreated trees were of poor vigour, while only 6% of treated trees were poor. There were also more good-vigour trees in the treated area (30%) than in the control (3%). *Armillaria* caused 3% mortality in the brushed area and 11% in the control. Aspen sprouted and suckered weakly after treatment, resulting in a large reduction in aspen abundance for 5 years. Five years after girdling, 58% of treated Douglas-fir were free of vegetation (versus 22% in the control) and the percentage of overtopped trees was 9% in the girdled area versus 47% in the control. Shrub cover and height decreased after brushing, whereas herb cover and height were unaffected.	Mather and Simard 1998l
Aspen	ICH	Girdling	Fd	74	Broadcast girdling of aspen increased the height and diameter growth of Douglas-fir and improved the vigour of the stand. Survival was the same (97%) in the girdled area and control; mortality was caused by *Armillaria* in the control and unknown causes in the girdled area. One year after girdling, treated aspen were starting to die and aspen cover was reduced to 14% (versus 44% in the control), but aspen height was not affected. Aspen sprouted and suckered weakly after treatment. One year after girdling, only 20% of Douglas-fir in the treated area were free of vegetation, as most girdled stems had not yet died. Shrub height increased slightly after treatment; shrub cover and herb height and cover were not affected.	Unpublished

TABLE A2.6 *Concluded*

Complex	BEC Zone	Brushing treatment	Conifer species	Sites	Interpretation	PROBE Memo Citation
Aspen	ICH	Cut, spray glyphosate	Pl	40	Five years after chemical treatment, pine stands were healthy regardless of treatment, but survival was lower in the control (89%) than in the treated area (97%). *Armillaria* caused 6% mortality in the control and 3% in the treated area; the other causes of mortality were not determined. Pine diameter growth, but not height growth, was slightly increased by the treatment. Five years after treatment, 60% of treated pine and 30% of untreated pine were free of vegetation. The percentage of untreated pine that were free of vegetation did not change over the measurement period, but the number of overtopped trees decreased slightly, suggesting that some untreated pine were starting to outgrow the aspen. The height and cover of aspen was greatly reduced for 5 years after herbicide treatment.	Mather and Simard 1998c
Aspen	MS	Triclopyr basal	Pl	64, 67	Aspen cover was greatly reduced by triclopyr application with no regrowth on treated stems 1 year after treatment. At one site (PROBE 67) where pine were tall (3 m) at the time of brushing, 80% of pine in the treated area were free of vegetation 1 year after treatment, and untreated pine were naturally outgrowing the aspen (the percentage of untreated pine that were free of vegetation increased from 25% before treatment to 50% 1 year later). At the other site where pine were 0.8 m tall at the time of brushing, 1 year after treatment only 31% of treated pine were free of vegetation and 58% were overtopped, while all untreated pine were overtopped both before and 1 year after treatment. At both sites, survival was 100% in both the chemically treated area and control. At one site, all trees were healthy, regardless of whether brushing was done, but at the other site there was a large increase in the percentage of poor-vigour and moribund trees in the untreated but not the treated area. At one site, pine diameter was 20% greater and leader growth was slightly greater in the brushed area than in the control 1 year after treatment. At the other site, leader growth decreased slightly after treatment and there was no diameter response. At both sites, herb cover increased slightly and shrub cover decreased after treatment. At one site, herb height increased and shrub height decreased, whereas at the other site there was no effect on the height of herbs and shrubs.	Unpublished